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TECHNICAL MEMORANDUM I

CANADIAN URANIUM TAILINGS DEPOSITS AND STRUCTURES

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THE TECHNOLOGY OF URANIUM TAILINGS COVERS
&
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THE STABILITY OF CONTROL STRUCTURES FOR URANIUM MILL TAILINGS

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MICROMEDIA

PREFACE

This technical memorandum is the first in a series of five technical memoranda which document the data, technology and evaluation studies undertaken to evaluate the long term stability of "Covers" and "Control Structures" for Canadian uranium mill tailings. The technical memoranda are:

Technical Memorandum	Title
TMI	Canadian Uranium Tailings Deposits and Structures
TMII	Characteristics Relevant to Releases of Three Generic Canadian Uranium Tailings Sites
TMIII	Methodology for Stability and Release Rate Evaluation
TMIV	Assessment of Alternative Evaluation Methods and Alternative Stabilization Practices
TMV	Evaluation of Cover and Structure Stability on Three Generic Canadian Uranium Tailings Sites

The conclusions reached and observations made as a result of these studies are summarized in two reports entitled:

REPORT 58901 THE TECHNOLOGY OF URANIUM TAILINGS COVERS

REPORT 58902 THE STABILITY OF CONTROL STRUCTURES FOR URANIUM MILL TAILINGS

This technical memorandum provides a brief description of the environment at the location of the various Canadian uranium tailings deposits and the characteristics of the tailings and deposits. The purpose of this description is to provide a general understanding of the nature and variety of uranium tailings deposits and the conditions in which they exist. The stability of the existing tailings control structures and contaminant release rates are briefly reviewed. An assessment is made of the present and long-term potential for cover and structure instability on a purely qualitative basis.

ACKNOWLEDGEMENTS

This study was conducted over a period of three months during which a large amount of data had to be obtained, reviewed and evaluated. It was only possible to complete the study in this short time period because of the willing and effective support provided by the Canadian uranium mining companies who were approached to provide data. Assistance was also provided in the review of the draft documents for this study by individuals employed by these mining companies.

We acknowledge with sincere appreciation the contributions of all who contributed to the study, of which the following made particularly large contributions:

Denison Mines Limited, including Mr. George Stenning and his staff and Mr. J.L. Chakravatti.

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This study was guided by the Scientific Authority, Mr. Grant Feasby, and his prompt and effective guidance, review and comment contributed largely to it successful completion.

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TECHNICAL MEMORANDUM I: CANADIAN URANIUM TAILINGS DEPOSITS AND STRUCTURES

I.1.0 LOCATION AND HISTORY OF TAILINGS DEPOSITS

I.1.1.A ONTARIO DEPOSITS

The Elliot Lake mining district is situated north of Lake Huron, midway between Sudbury and Sault Ste. Marie. Uranium mining and milling has been ongoing in the area since 1954.

Within this time frame a total of 13 mines and 11 mills have been in operation. To date over 100 million tonnes of tailings have been produced.

Tailings and process water from the mills have been deposited in ten separate tailings impoundments, as shown on Figure I.1.A-1. Currently only four of these areas are active, three of which are operated by Rio Algom Limited and one by Denison Mines Limited. It is estimated, based on existing ore reserves, approximately 500 million tonnes of tailings could eventually be deposited within the Elliot Lake area.

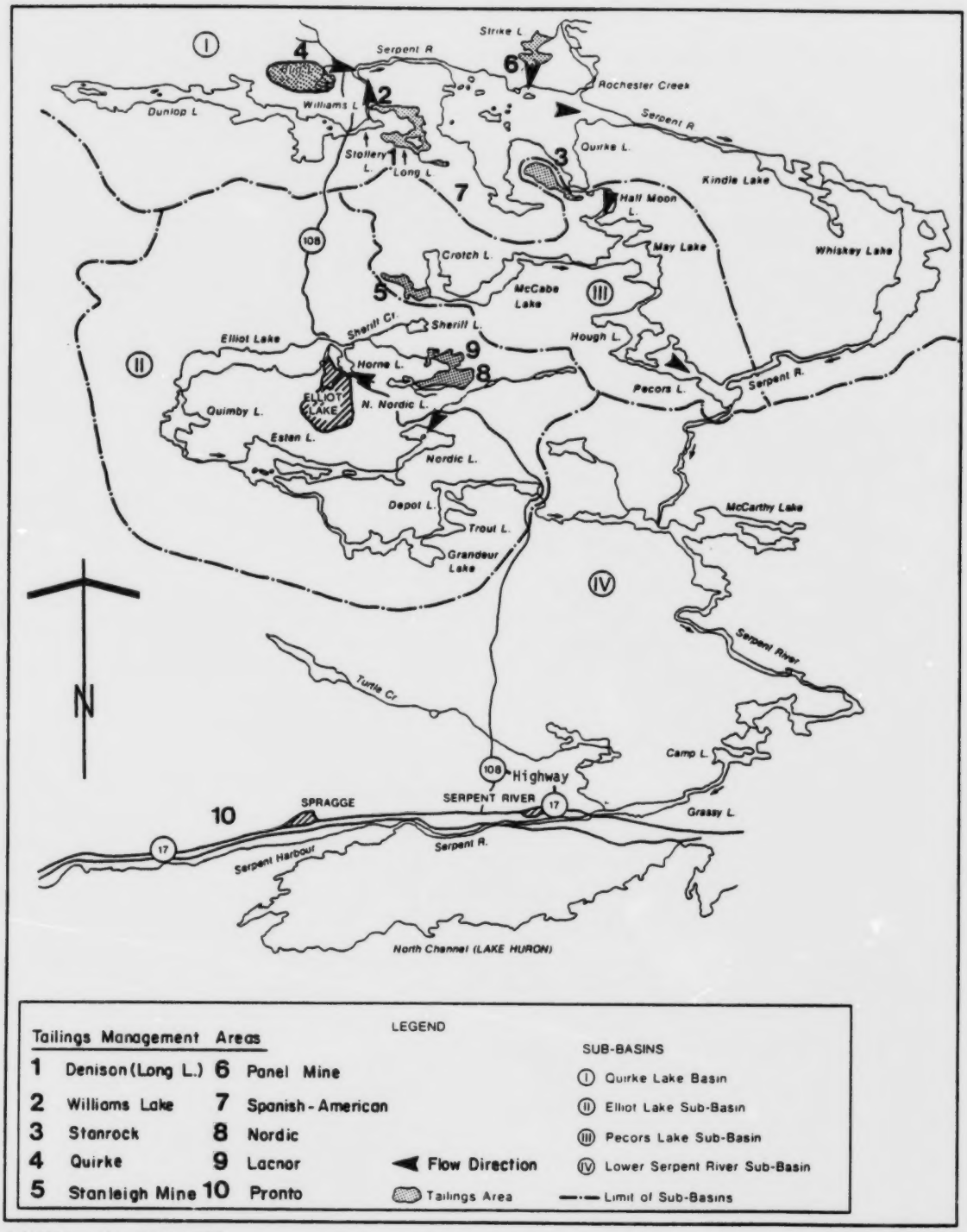
Denison Mines Limited has the responsibility of managing three tailings areas, namely Denison Mine Tailings Management Area (formerly Long Lake), Stanrock Tailings Management Area and Williams Lake Tailings Management Area, the latter two being the inactive disposal sites. Rio Algom Limited is responsible for seven tailings retention areas, specifically; Quirke Mine, Stanleigh Mine, Panel Mine, Spanish-American, Lacnor, Nordic and Pronto Tailings Management Areas. The former four sites are presently active.

The Pronto Mine produced some uranium tailings but the vast majority of tailings produced at the Pronto Mine were copper tailings. For this reason the Pronto Tailings Management Area is atypical relative to the other nine tailings impoundments and is therefore, excluded from all subsequent text, tables and figures in this technical memorandum.

A brief summary of the history of each deposit is given in Table I.1.A-1. A more extensive history and description of each management area is discussed in Section I.4.0.

I.1.1.B SASKATCHEWAN DEPOSITS

The major belt of uranium mineralization occurs in northern Saskatchewan, generally north of 57° latitude (Figure I.1.B-1). The area is remote, being more than 600 km north of Saskatoon, the major population centre servicing the industry. Mining in the area has been onging since development work begin on the Eldorado Mining and Refining Limited property at Beaverlodge in 1948. Milling began on that property in 1953. By 1957, there were 7 active mines in northern Saskatchewan. By 1970, only one, the Beaverlodge Mine, remained in production. A new generation of mines began production in 1975 when the Gulf Minerals Canada Limited (GMCL) mill began production at the Rabbit Lake property. There are presently 3 active mills



SOURCE - Marshall, 1982

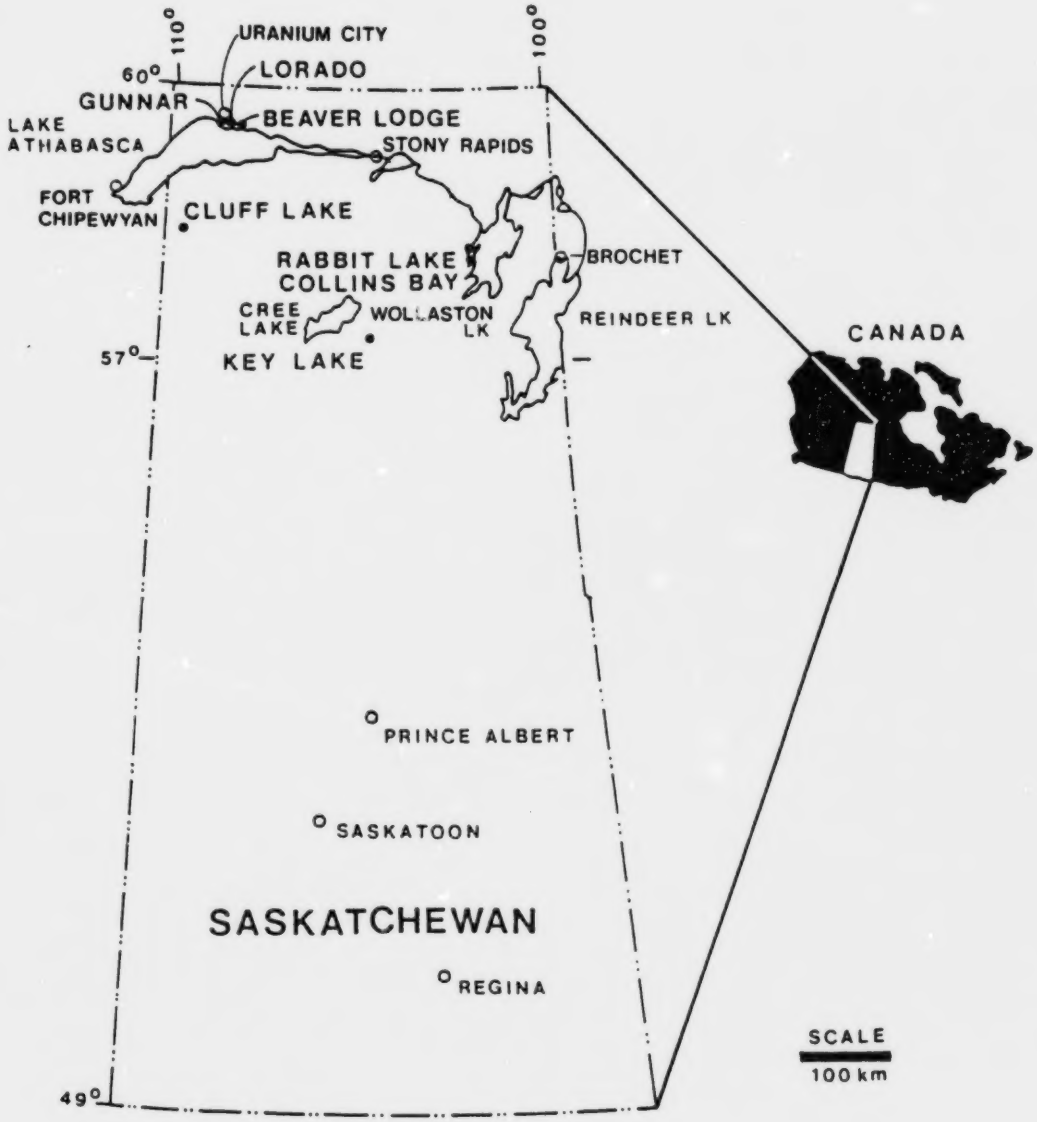
TAILINGS MANAGEMENT AREAS, ELLIOT LAKE, ONTARIO

FIGURE I.1. A-1

TABLE I.1.A-1

MAJOR TAILINGS MANAGEMENT AREAS IN ELLIOT LAKE

TAILINGS MANAGEMENT AREA	YEARS OF OPERATION	TOTAL TONNAGE DEPOSITED (million tonnes)	AREA (ha)
DENISON MINES LIMITED			
DENISON MINE (Long Lake)	1960-present	45	182
WILLIAMS LAKE	1957-1959	0.9	7.3
STANROCK	1957-1964	7.5	61
RIO ALGOM LIMITED			
QUIRKE MINE	1956-1961 1968-present	35.4	162
STANLEIGH MINE	1958-1964 1983-present	10.34	400
PANEL MINE	1958-1961 1978-present	9.37	70
SPANISH-AMERICAN	1958-1959	0.45	10
LACNOR	1957-1960	2.7	24
NORDIC	1957-1968	12	85



TAILINGS MANAGEMENT AREAS, SASKATCHEWAN

FIGURE I.1.B-1

in the area. A summary of the major tailings management areas in Saskatchewan is given in Table I.1.B-1.

TABLE I.1.B-1

MAJOR TAILINGS MANAGEMENT AREAS IN SASKATCHEWAN

MINE LOCATION	TYPE	YEARS OF OPERATION	TOTAL TONNAGE DEPOSITED (million tonnes)	AREA (ha)
Beaverlodge	Lake Discharge	1953-82	6*	
Gunnar	Unengineered	1955-63	4.4	74.8
Lorado	Unengineered	1957-61	0.55	14.2
Rabbit Lake	Engineered Dams	1972-1975-85	5.9 (est)	97.6
Cluff Lake	Engineered Dams	1981-present	7.5	94-172**
Key Lake	Subaerial	1983-present	4.2	45
Collins Bay	Pit Disposal	1985-present	3.5 (est)	27 (est)

* approximately 10 million tonnes of tailings were produced, but about 4.3 million tonnes were used as mine backfill.

**future potential of 172 ha.

(from Swanson and Abouguendia, 1981; Stearns-Roger Incorporated, 1976a; Knight and Piesold Ltd., 1981a; MacLaren Engineers Inc., 1984).

I.2.0 ENVIRONMENTAL SETTING

I.2.1.A TOPOGRAPHY AND GEOMORPHOLOGY, ONTARIO

The Elliot Lake area borders the Superior and Southern Provinces of the Canadian Shield. As such the topography is characterized by bedrock knolls and ridges separated by lower areas consisting of numerous lakes and swamps. Elevation differences generally are in the order of 50 metres or less.

The bedrock stratigraphy in the Elliot Lake area, as identified by Robertson, 1981, is comprised of three major lithologic units, namely:

1) Archean basement rocks,
2) Huronian rocks, and
3) Post Huronian intrusive rocks.

The Archean basement complex, which is comprised of granitic intrusives and meta-volcanics, is overlain unconformably by a sequence of sedimentary and metasedimentary rocks (Huronian) of Proterozoic age up to 2,000 m thick. The local ore zone occurs in a 0.5 to 3 metre thick pyritized quartz-pebble conglomerate bed located near the base of the sedimentary sequence and is generally of low grade (0.5 to 1.5 kilograms per tonne; Golder, 1984). This Huronian Supergroup has been folded and faulted during the Hudsonian Orogeny into an east-west synclinal structure, known as the Quirke syncline. Throughout the Huronian Supergroup are Post-Huronian intrusive rocks, comprised of granite and diabase sills and dykes. The regional metamorphism of these sedimentary rocks is to the greenschist facies (Pullen and Davis, 1981).

The Proterozoic rocks are predominantly comprised of quartzites, arkoses, argillites, siltstones, minor carbonates and conglomerates.

Pullen and Davis, 1981, describe the regional faults as tending to occur at a 5 to 6 km spacing and, with the exception of a major overthrust fault, are steeply dipping and strike generally northwest-southeast. Local faulting tends to be more intense (0.8 to 1.2 features per square km) and, while generally steeply dipping, exhibit variable strike and persistence.

Overlying the bedrock are thin Pleistocene deposits comprised of till overlain in many instances by glacial outwash and recent organic deposits. During the Wisconsin Glaciation, ice advanced over the area toward the south-southwest and deposited a thin, discontinuous veneer of till over much of the bedrock surface. In a few local areas, where bedrock valleys have been infilled, the thickness of the till can be in the order of 30 m. The deposition of the till has been identified to be both ablation and lodgement in origin. The ablation tills are the more predominant in the area and are usually of silty sand texture mixed with gravel and cobbles.

The till surface is undulating in nature, especially where the drift thickness is in excess of 1 m. Some ice-meltwater landforms are also present as hummocky deposits of sand, gravel and till complexes.

Other glacial-age landforms identified in the area include stratified outwash sand plains and glaciolacustrine deposits of silts and clays which have been deposited during deglaciation. These deposits are commonly associated with lower lying areas between bedrock knobs and ridges and are of limited extent and thickness. These stratified lake deposits are typically underlain by the till at depth.

Since deglaciation, recent deposits, i.e. flood plain alluvium, have been deposited within the valleys of most drainage courses. Organic deposits have accumulated in many low, poorly drained depressions in the area.

The numerous interconnected lakes now present in the Elliot Lake area are associated with and are parallel to bedrock lineations and terminal moraines. This parallel orientation is thus a reflection of the glacial ice front, from a series of stagnant ice stages extending from northwest to southeast.

Two types of ground water flow systems exist in the area, i.e. local flow and that of regional extent. Many small local basins are created and controlled by the bedrock topography. Within these basins, the sands and gravels associated with the outwash plains, river valley terraces and alluvium are generally the best aquifers. The permeability of the granular deposits are generally in the order of 10^{-5} metres per second (m/s). Glacial tills, the most predominant soil unit, are less permeable with permeabilities in the order of 10^{-7} m/s and thus often form aquitards to flow, as is the case with the lacustrine clays and silts. The lakes and rivers are local discharge areas, i.e. they receive base flow discharge from ground water. The soils that border them are important sources of ground water storage. The many swampy areas of the landscape also represent discharge zones and high water tables. Some of these, however, may be seasonally perched.

Flow in the bedrock is more complex and is controlled by fractures or structural discontinuities. Permeabilities in the bedrock are low except at regional discontinuities. With depth, open joints are less common and permeabilities decrease. However, in some cases, shear zones at depth result in exceptions to this generalization. Golder, 1984, state, based on detailed foundation investigations at tailings dams within the area, the permeability of the bedrock mass is in the order of 10^{-5} to 10^{-7} m/s near ground surface but decreases to less than 10^{-7} m/s at a depth of 15 metres below the rock surface. However, due to fracturing, the permeability of the bedrock increases close to features such as faults and dykes, with maximum permeabilities of 5×10^{-5} m/s close to ground surface and permeabilities of 10^{-6} to 10^{-7} m/s at a depth of 15 to 30 metres below the surface of the rock.

The Elliot Lake mining district, including each of the tailings management areas shown on Figure I.1.A-1, are within the Serpent River basin which has a watershed of about 1.4×10^{5} hectares and discharges into Lake Huron - North Channel via the Serpent River. The mean annual discharge from the basin is about 21 cubic metres/second (Pullen & Davis, 1981). From a regional point of view, the Serpent River is both a local and regional discharge feature.

I.2.1.B TOPOGRAPHY AND GEOMORPHOLOGY, SASKATCHEWAN

All of the uranium mines are within the Canadian Shield, a glacially scoured complex of geologically ancient rocks (Figure I.2.B-1). The oldest rocks are ancient Archean granites which comprise the basement complex. These are more than 2 billion years old. They are overlain and interfolded with a series of Aphebian age (1.7 to 2.0 billion years old) metamorphosed, deformed and recrystallized sediments which were derived from the basement rocks. The Athabasca Formation, consisting of sandstone of Helikian age, was laid down on the older rocks approximately 1 billion years ago. The uranium mineralization is usually found near the contact between the Athabasca sandstone and the older rocks, or within highly altered Aphebian rocks. Uranium mineralization is commonly associated with significant structures and with arsenic, iron, nickel, cobalt, copper, zinc, molybdenum, lead, vanadium and sometimes minor thorium and selenium. A host of other minor minerals plus clay and graphite are commonly present.

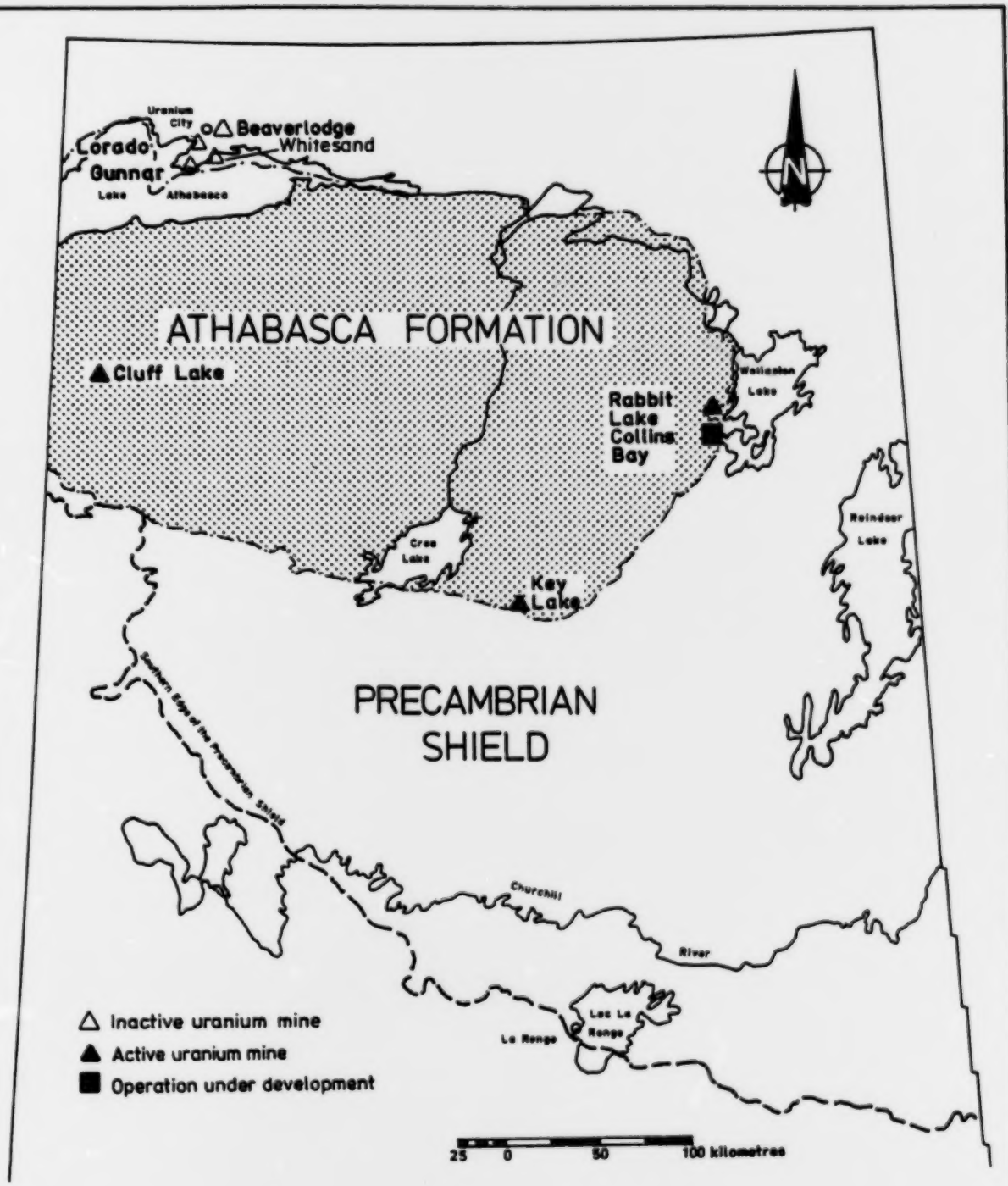
The surface of the Precambrian rocks has been extensively scoured by glacial erosion and covered with a thin veneer of glacial and proglacial sediments. The elevation of the ground surface varies from approximately 213 m ASL at Lake Athabasca to a maximum of 600 m ASL on local uplands. The local relief is generally less than 100 m. Glacial sediments are generally thin (less than 50 m) and comprised of coarse textured glacial silt and outwash sand derived from the Athabasca sandstone. Silt may be present locally, but clay is virtually absent. Topographic depressions are often infilled with peat. The entire area is within the zone of discontinuous permafrost and the peat filled depressions often contain ice-rich, permanently frozen soil.

The regional drainage is generally poorly integrated, being comprised of many land-locked lakes and bogs. Two major drainage systems prevail. Most of the Athabasca basin drains to Lake Athabasca and through the Mackenzie River drainage system to the Arctic Coast. The remainder of the Shield drains to the Churchill River system and, eventually, Hudson Bay. The surface water is generally of a very high quality with a very low mineral content, most often with a total dissolved solid content of less than 200 milligrams per litre (mg/L) and very often less than 100 mg/L. The pH of the water varies from about 5.5 to 8, but may be as low as 3 in stagnant muskeg areas.

Numerous elevated water bodies and peat bogs provide ample recharge for the groundwater systems. Major aquifers include glacial outwash plains comprised primarily of sand, glacial till strata and fractured bedrock. The drift and fractured bedrock is relatively permeable, but the hydraulic conductivity of the bedrock generally decreases with depth. The flow systems in the bedrock are controlled in large part by structural discontinuities. The groundwater is generally very good, closely reflecting the surface water quality.

I.2.2.A CLIMATE, ONTARIO

Climate has a multifaceted influence on the surface stability and overall structural integrity of tailings disposal areas. Influence can vary from seasonal effects in the area of tailings disposed (e.g. above or below



GEOLOGY OF NORTHERN SASKATCHEWAN

FIGURE I. 2. B-1

average precipitation or temperatures during the plant growing season) to global long term changes, measured in hundreds of years, which would have a major effect on climax vegetation communities presently characteristic of the Great Lakes - St. Lawrence Forest and Boreal Forest Regions.

Based on climatological station data for Elliot Lake from 1951 to 1980, a water budget has been calculated using the Thornthwaite method (Thornthwaite and Mather, 1957). The mean monthly temperatures at Elliot Lake range from about -12° C in January to approximately 18° C in July. The mean monthly temperatures are shown on Figure I.2.A-1. Based on historical data there are approximately 183 days of frost per year in this area.

The mean monthly precipitation for the area ranges from 58 mm in March to 121 mm in September. Typically, most months have 59 to 82 mm of precipitation, except September and November during which time in excess of 110 mm may fall. The normal distribution of mean monthly precipitation is shown on Figure I.2.A-2. The mean annual precipitation is approximately 926 mm. The coefficient of variation of precipitation is 0.035, which is low, indicating a generally even distribution of precipitation throughout the year.

The potential evapotranspiration at Elliot Lake is estimated to be 542 mm/year, leaving a potential water surplus of 384 mm. The distribution of surplus water is shown on Figure I.2.A-3 and in Table I.2.A-1. The water available for infiltration is usually less than the water surplus, depending on the topography and geology of the terrain, i.e. reduction of infiltration due to the amount of surface runoff. Pullen & Davis, 1981, suggest approximately 100 mm/year infiltrates into the ground.

The variability in the potential water surplus has been calculated using the standard deviations of annual meteorological data. It is estimated that the potential water surplus would be within the range of 351 mm to 418 mm per year, for 13 out of 20 years.

Figure I.2.A-4 is included to show the likely ranges of water balances on a monthly basis for 13 out of 20 years. These ranges are based on one standard deviation of data about the mean value. Because the water balance data from individual months may differ in how much they vary from the norm (and to a certain extent cancel out), one cannot simply add the monthly ranges shown in Figure I.2.A-4 and consider it as an "annual" range.

Table I.2.A-2 shows the precipitation intensity, duration and frequency (IDF) data for Rayner, Ontario. This meteorological station has been used because IDF data does not exist for Elliot Lake.

Table I.2.A-3 contains the calculated lake evaporation data for the Ottawa CDA station (44° 23'N latitude). The Canadian meteorological station from which these data are obtained has a latitude closest to Elliot Lake (46° 24'N latitude). The next closest station to Elliot Lake is at Camerons Falls (49° 09'N latitude).

The wind rose pattern for the Elliot Lake area is shown on Figure I.2.A-5. These data were collected between January, 1980 and December, 1982 at the

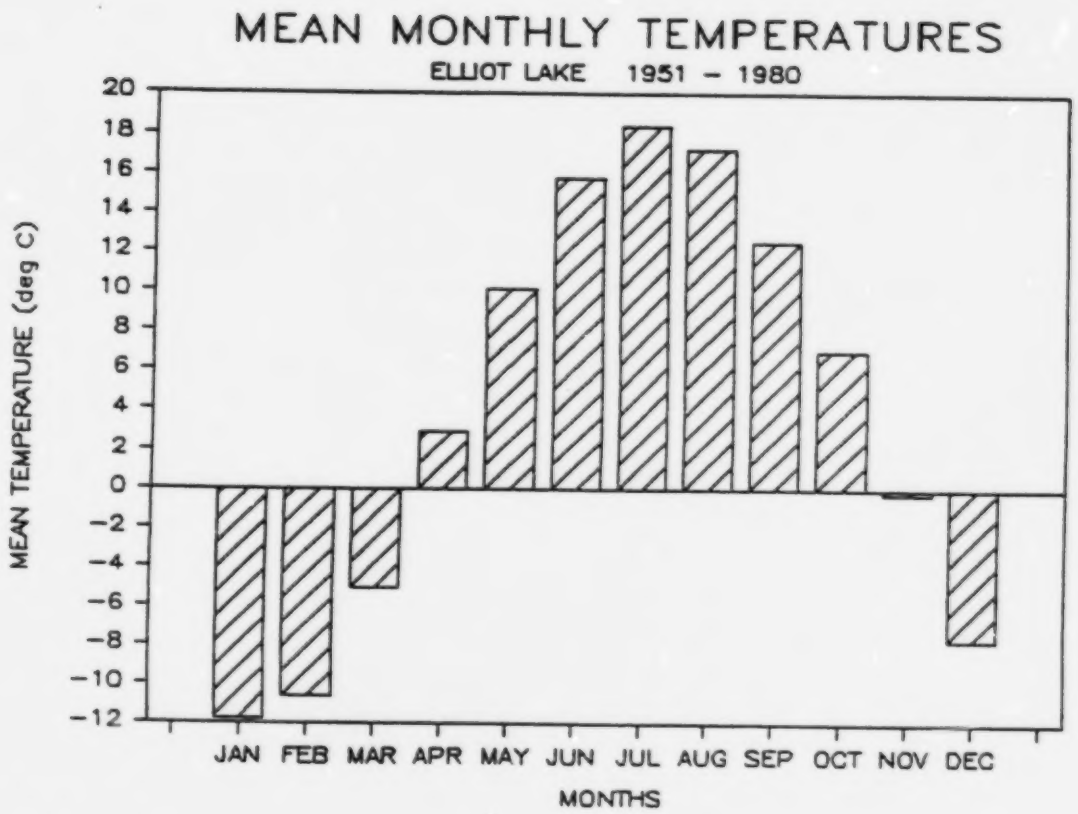

MEAN MONTHLY TEMPERATURES
ELLIOT LAKE 1951 - 1980
MEAN TEMPERATURE (deg C)
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTHS

FIGURE I.2.A-1

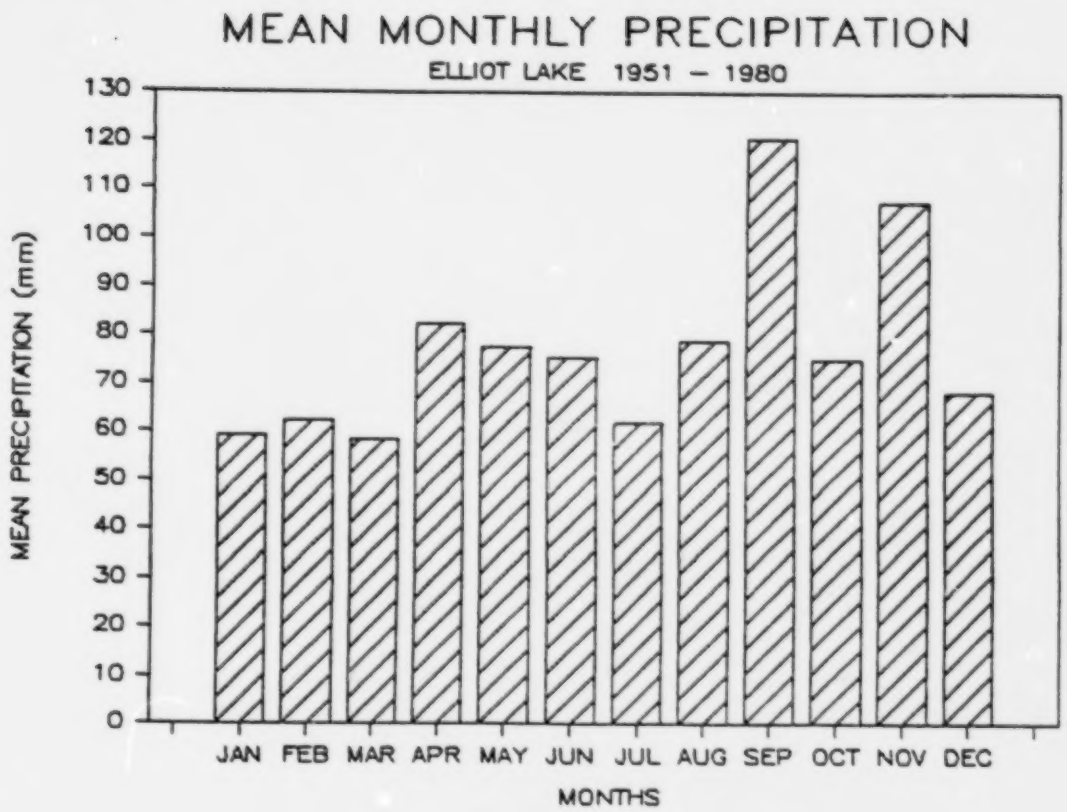

MEAN MONTHLY PRECIPITATION
ELLIOT LAKE 1951 – 1980
MEAN PRECIPITATION (mm)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTHS

FIGURE I.2.A-2

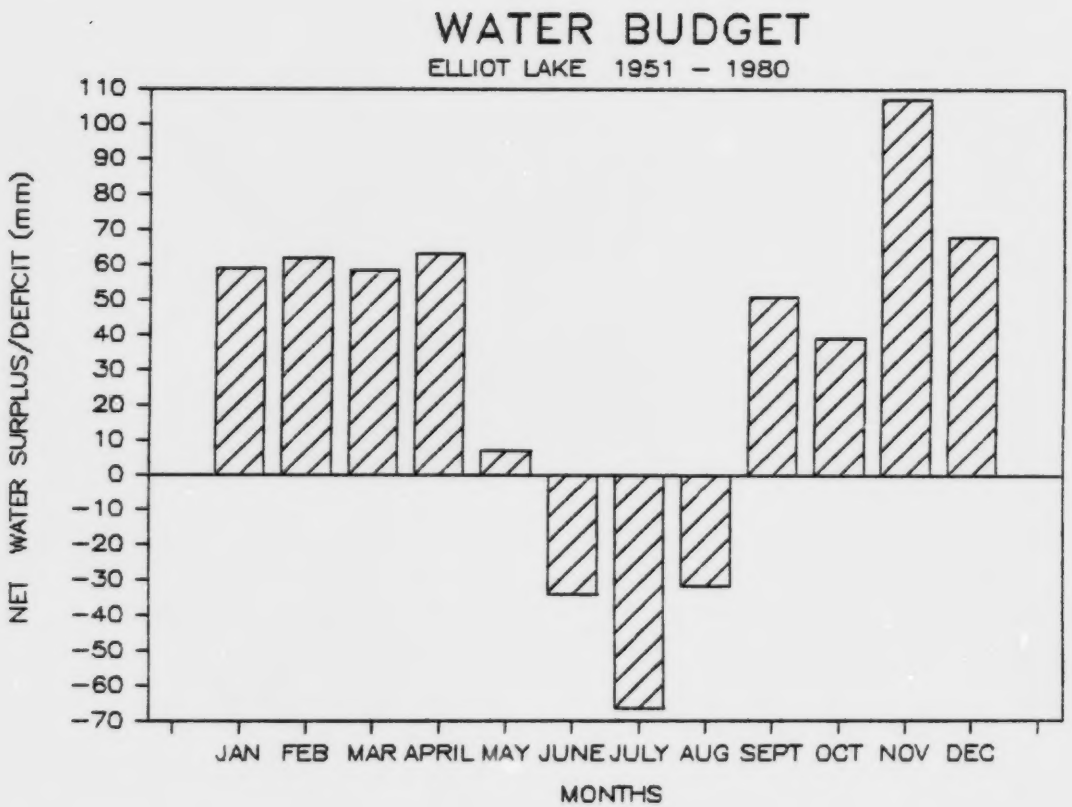

WATER BUDGET
ELLIOT LAKE 1951 – 1980
NET WATER SURPLUS/DEFICIT (mm)
110
100
90
80
70
60
50
40
30
20
10
0
−10
−20
−30
−40
−50
−60
−70
JAN FEB MAR APRIL MAY JUNE JULY AUG SEPT OCT NOV DEC
MONTHS

FIGURE I.2.A-3

TABLE I.2.A-1

AVERAGE WATER BUDGET CALCULATION FOR ELLIOT LAKE

MONTH	MEAN TEMP °C	ADJ EVT mm	MEAN PRECIP mm	NET WATER BALANCE mm
JAN	-11.7	0	59.3	59.3
FEB	-10.6	0	62.1	62.1
MAR	-5.1	0	58.3	58.3
APRIL	2.9	18.8	82.3	63.5
MAY	10.1	70.4	77.5	7.1
JUNE	15.8	109.1	75.5	-33.6
JULY	18.4	127.8	61.7	-66.1
AUG	17.2	110.3	78.9	-31.4
SEPT	12.5	69.6	120.5	50.9
OCT	7.0	35.8	74.9	39.1
NOV	-0.2	0	107.2	107.2
DEC	-7.7	0	68.1	68.1
TOTAL	4.1	541.8	926.3	384.5

TOTAL PRECIPITATION	926.3	mm
POTENTIAL EVAPOTRANSPIRATION	541.8	mm
NET WATER BALANCE	384.5	mm

TABLE I.2.A-2

PRECIPITATION INTENSITY, DURATION AND FREQUENCY DATA
FOR RAYNER, ONTARIO, 1954-1970

PRECIPITATION (mm)

STORM LENGTH (hours)	RETURN PERIOD (YEARS) 2	5	10	25	50	100
5M	7.78	0.57	12.42	14.76	16.49	18.21
10M	10.54	14.26	16.73	19.85	22.16	24.46
15M	12.16	16.63	19.59	23.33	26.10	28.86
30M	15.37	21.88	26.20	31.65	35.69	39.71
1H	18.82	26.29	31.24	37.49	42.13	46.74
2H	24.46	32.89	38.48	45.53	50.76	55.96
6H	35.72	43.07	47.95	54.10	58.67	63.21
12H	43.80	53.21	59.45	67.32	73.16	78.96
24H	54.34	73.68	86.51	102.70	114.70	126.64

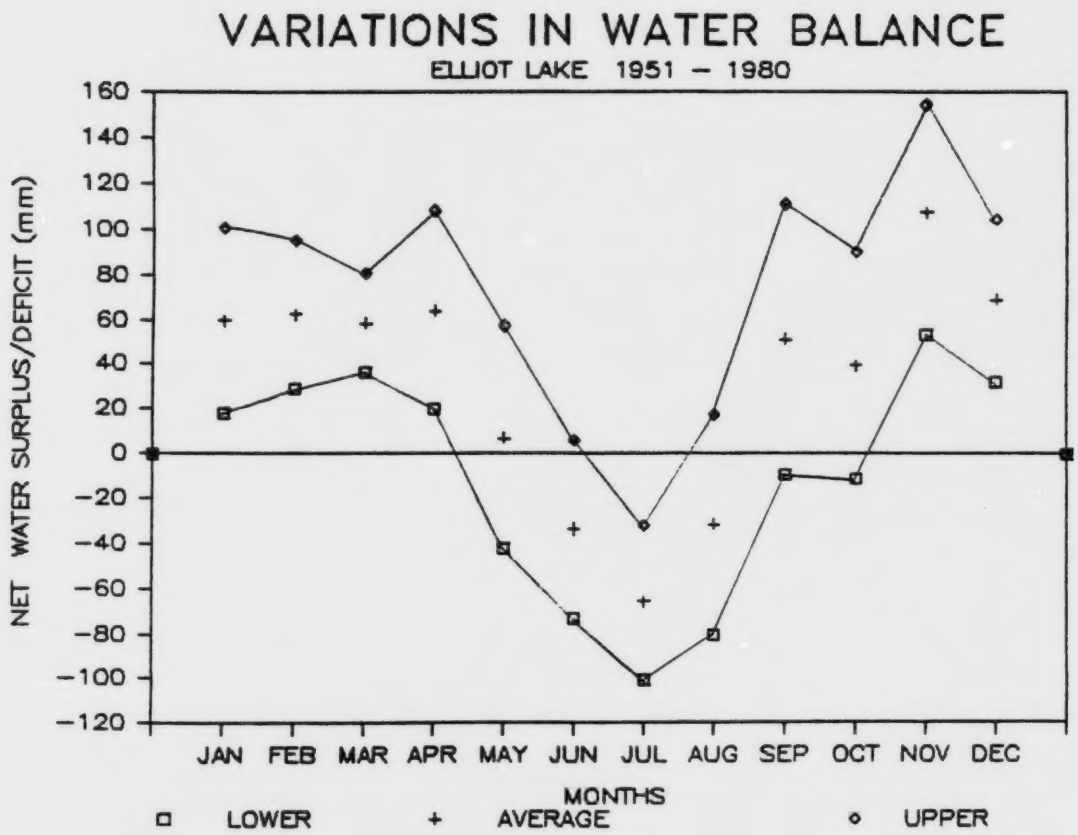
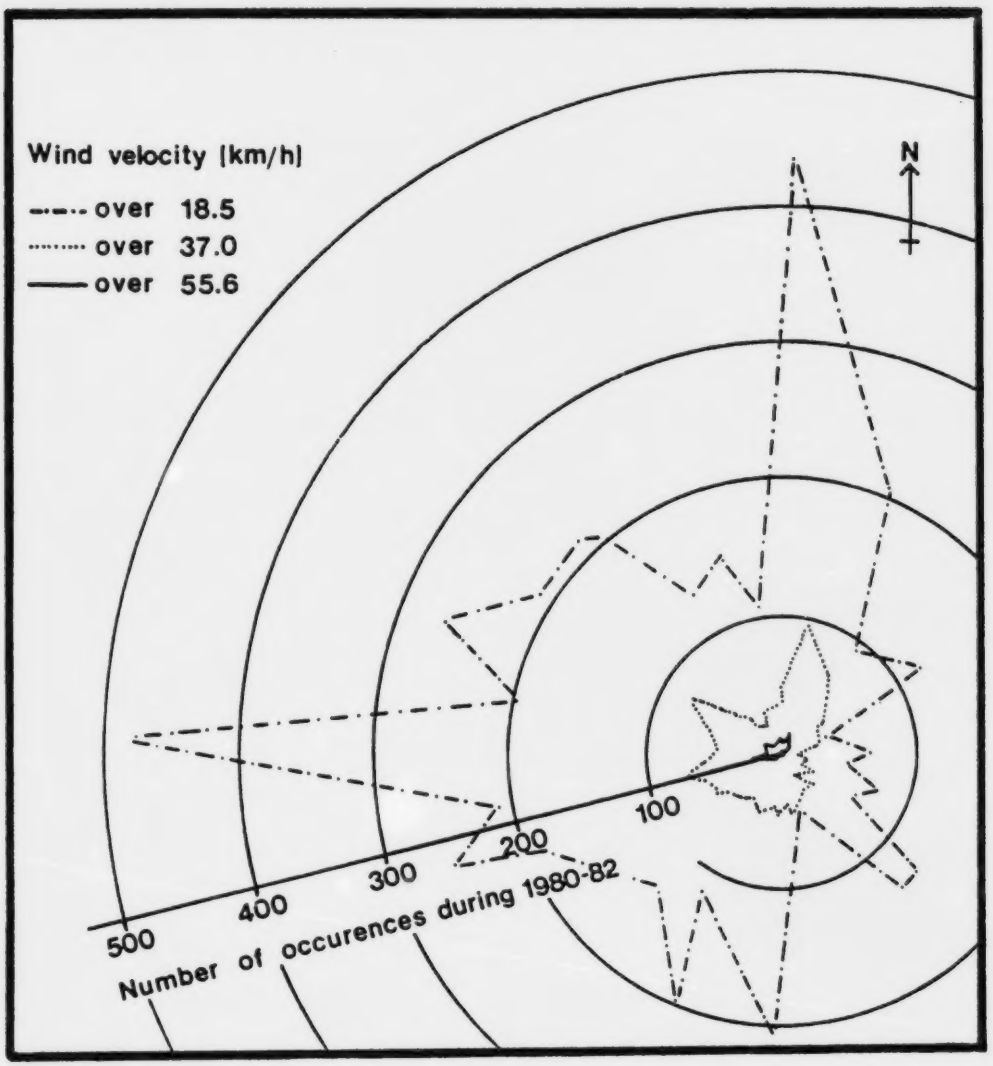

VARIATIONS IN WATER BALANCE
ELLIOT LAKE 1951 – 1980
NET WATER SURPLUS/DEFICIT (mm)
160
140
120
100
80
60
40
20
0
−20
−40
−60
−80
−100
−120
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
MONTHS
LOWER
AVERAGE
UPPER

FIGURE I.2.A-4

TABLE I.2.A-3

CALCULATED LAKE EVAPORATION DATA
FOR OTTAWA CDA, 1951-1980

MONTH	EVAPORATION (mm) MEAN	STD DEV
APR	0.0	0.0
MAY	112.7	18.3
JUN	130.9	16.0
JUL	141.4	14.3
AUG	112.0	12.9
SEP	73.3	18.4
OCT	40.7	8.3
NOV	0.0	0.0
TOTAL	611.0	



FREQUENCY OF WIND DIRECTION
Elliot Lake
Airport

FIGURE I.2.A-5

Elliot Lake Airport, which is located approximately 15 km south of the majority of the tailings management areas. Winds having a velocity of greater than 18.5, 37, and 55.6 km/h accounted for 31.0, 6.7, and 0.6% of the record, respectively (Dave et al, 1985). The most predominant prevailing winds are from the west, north and northwest directions. The Elliot Lake Airport has, until recently, been a contract station collecting only select meteorological data. Therefore, more detailed wind data are not available.

I.2.2.B CLIMATE, SASKATCHEWAN

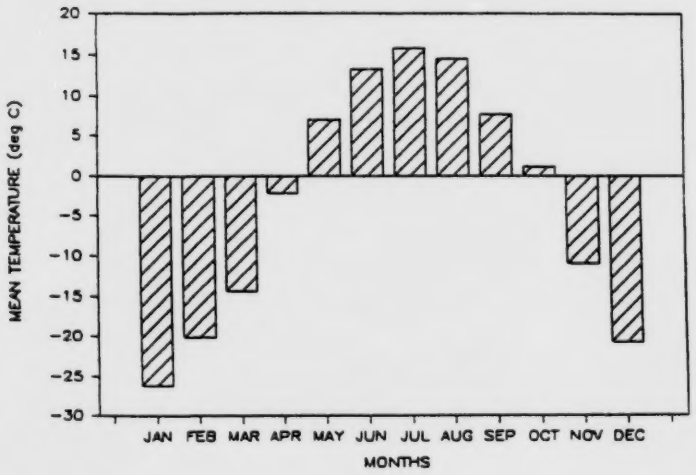
The climate in the mining areas is characterized as a short cool summer boreal forest climate (Richards and Fung, 1969). Whiting et al (1982) report that a quasi-permanent high pressure ridge dominates the circulation over Lake Athabasca in summer while a principal storm track from the Alaska low pressure area enters the study area in June. All of the tailings management areas fall between the -1 and -5°C isotherm.

Meteorological records from Uranium City, Cree Lake, Stony Rapids, Brochet and Fort Chipewyan have been used to describe the area climate. Data from Uranium City, Cree Lake, and Fort Chipewyan have been used to characterize the climate of Cluff Lake, Gunnar and Lorado. The climate for the Key Lake area has been characterized from Cree Lake data. Meteorological data from Stony Rapids and Brochet have been reviewed to characterize the climate of the Rabbit Lake area.

Mean monthly temperature and precipitation, average water budget and variations in the water budget are presented in Figures I.2.B-2 to -13. Average water budget calculations are shown on Tables I.2.B-1 to -3. The data indicate that mean annual precipitation varies from approximately 380 to 414 mm across the area with approximately two thirds occurring as rainfall. Mean daily temperatures vary from approximately -28°C in January to +16°C in July and extreme temperatures from about -52°C to +40°C. The mean period of snow cover is from approximately 15 October to 15 May annually and the mean date of ice covering and clearing the lakes is approximately 01 November and 25 May, respectively.

A review of wind velocities indicate that these are relatively uniformly distributed. The mean wind velocity at La Ronge is 10 km per hour and is relatively constant throughout the year. The wind direction is relatively well distributed with a minor predominance of southeasterly and northwesterly winds. McInnis (1985) estimates the peak hourly wind to be between 83 and 93 km per hour for the 10-year frequency; 95 and 103 km per hour for the 30-year frequency; and, 101 and 119 km per hour for the 100-year frequency.

Extreme precipitation events have been addressed by Whiting et al (1982) and Knight and Piesold Ltd. (1981). Table I.2.B-4 presents a summary of extreme and mean precipitation events derived from the Fort Smith data and deemed to be appropriate for the Uranium City area. The values obtained are consistent with those utilized in the design of the Key Lake and Rabbit Lake tailings systems (Key Lake Mining Corporation (KLMC), 1981; Geocon Ltd., 1973). However, the probable maximum precipitation (PMP) appears to be greatly underestimated. Wigham (1981 personal communication) reported a

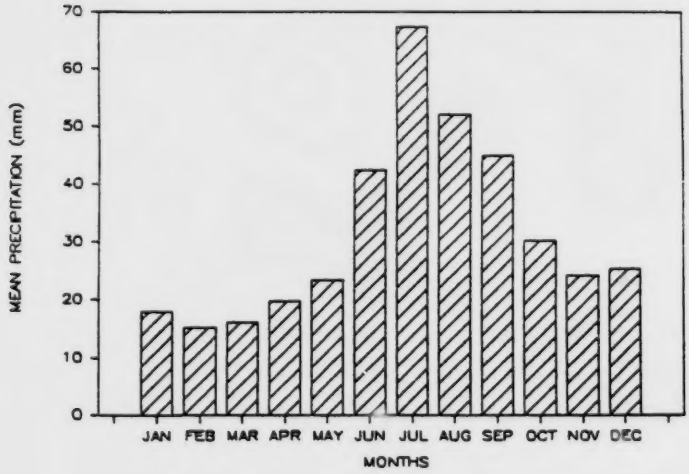


MONTHLY TEMPERATURES

FOR GUNNAR, LORADO AND CLUFF LAKE TAILINGS AREA

(FROM CLIFTON ASSOCIATES LTD. 1985)

FIGURE I.2.B-2

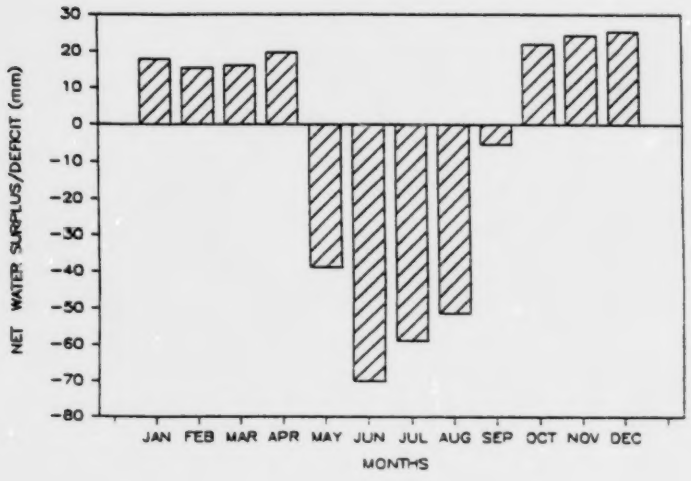


MONTHLY PRECIPITATION

FOR GUNNAR, LORADO AND CLUFF LAKE TAILINGS AREA

(FROM CLIFTON ASSOCIATES LTD. 1985)

FIGURE I.2.B-3

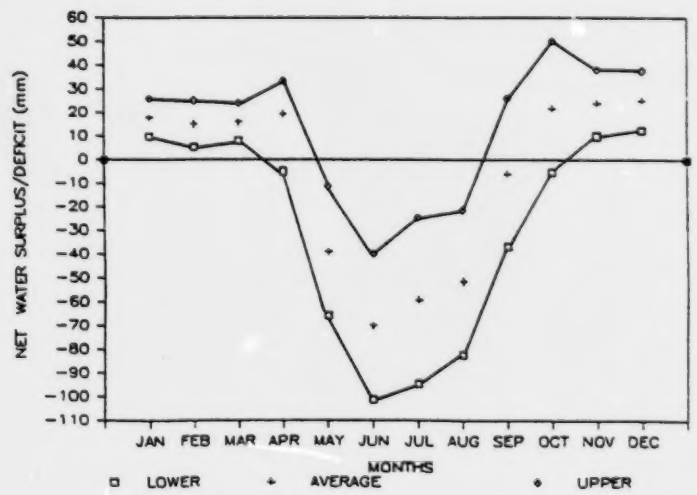


WATER BUDGET

FOR GUNNAR, LORADO AND CLUFF LAKE TAILINGS AREA

(FROM CLIFTON ASSOCIATES LTD. 1985)

FIGURE I.2.B-4

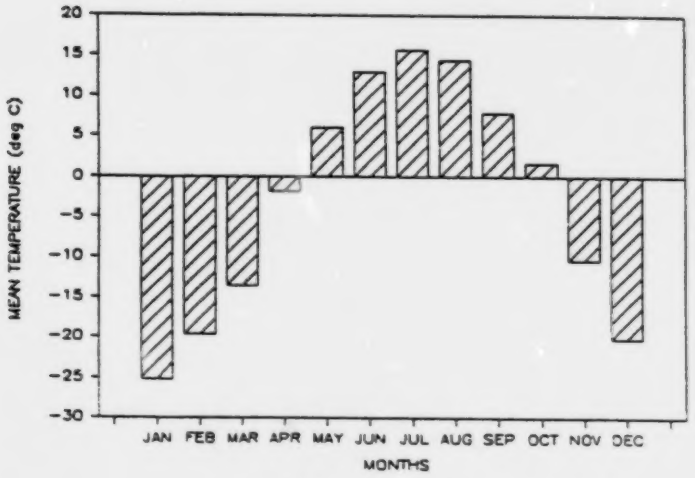


VARIATIONS IN WATER BALANCE

FOR GUNNAR, LORADO AND CLUFF LAKE TAILINGS AREA

(FROM CLIFTON ASSOCIATES LTD. 1985)

FIGURE I.2.B-5

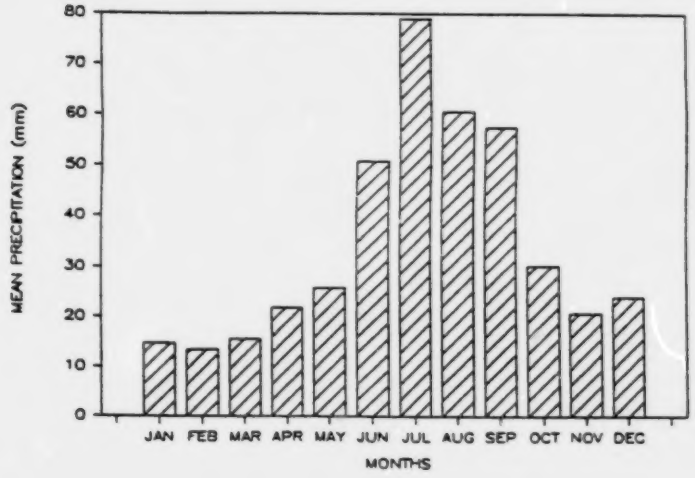


MONTHLY TEMPERATURE

FOR KEY LAKE TAILINGS AREA

(FROM CLIFTON ASSOCIATES LTD. 1985)

FIGURE I.2.B-6

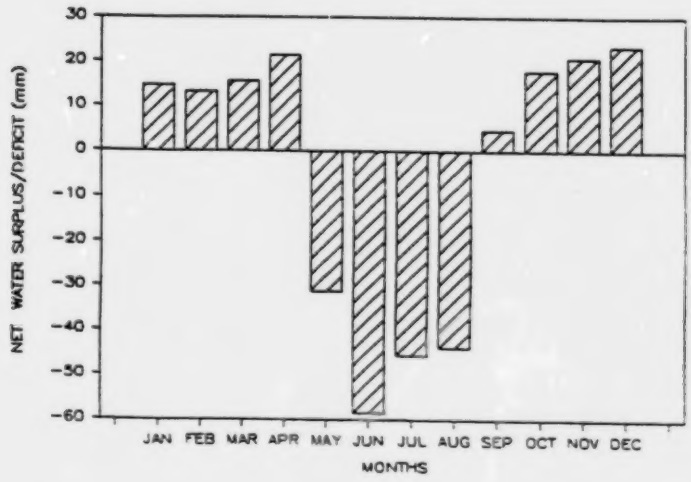


MONTHLY PRECIPITATION

FOR KEY LAKE TAILINGS AREA

(FROM CLIFTON ASSOCIATES LTD. 1985)

FIGURE I.2.B-7

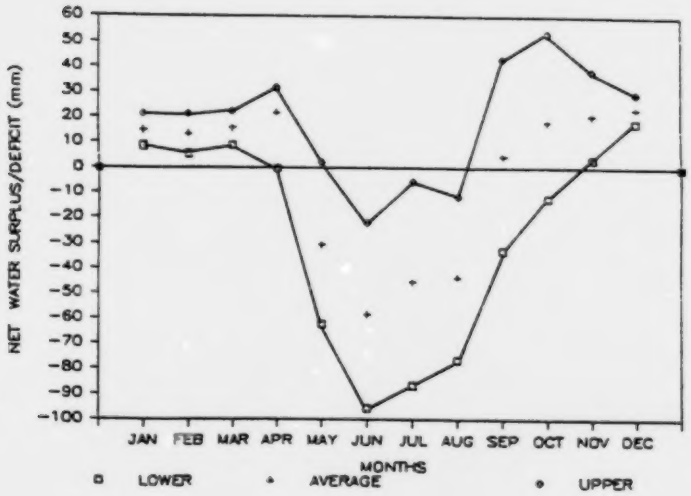


WATER BUDGET

FOR KEY LAKE AREA

(FROM CLIFTON ASSOCIATES LTD. 1985)

FIGURE I.2.B-8

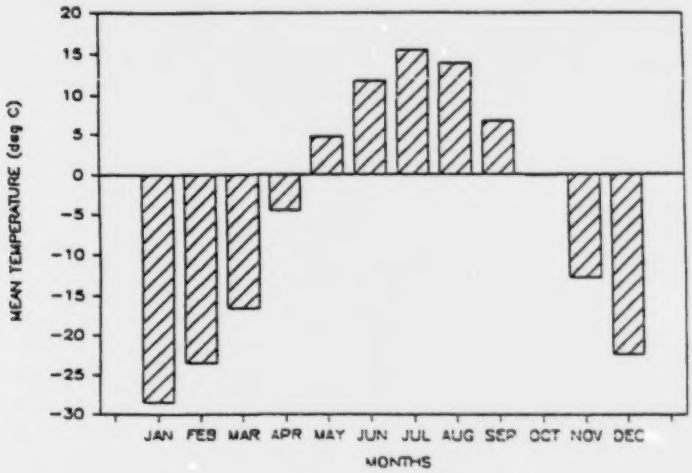


VARIATIONS IN WATER BALANCE

FOR KEY LAKE TAILINGS AREA

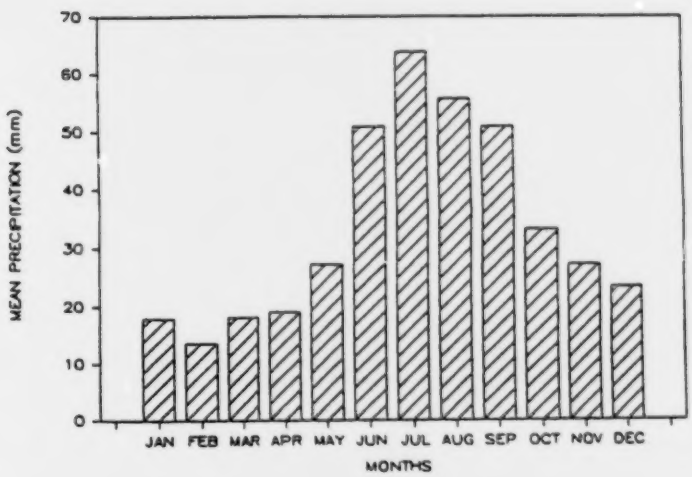
(FROM CLIFTON ASSOCIATES LTD. 1985)

FIGURE I.2.B-9



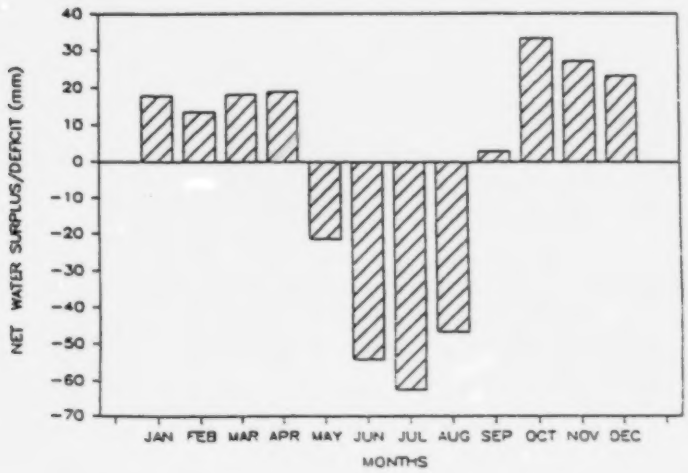
MONTHLY TEMPERATURES
FOR RABBIT LAKE TAILINGS AREA
(FROM CLIFTON ASSOCIATES LTD. 1985)

FIGURE I.2.B-10



MONTHLY PRECIPITATION
FOR RABBIT LAKE TAILINGS AREA
(FROM CLIFTON ASSOCIATES LTD. 1985)

FIGURE I.2.B-11

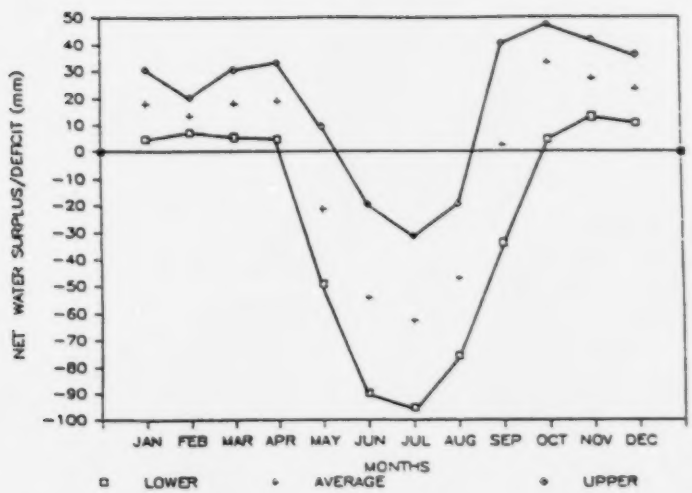


WATER BUDGET

FOR RABBIT LAKE TAILINGS AREA

(FROM CLIFTON ASSOCIATES LTD. 1985)

FIGURE I.2.B-12



VARIATIONS IN WATER BALANCE

FOR RABBIT LAKE TAILINGS AREA

(FROM CLIFTON ASSOCIATES LTD. 1985)

FIGURE I.2.B.13

TABLE I.2.B-1

AVERAGE WATER BUDGET CALCULATION
FOR GUNNAR, LORADO AND CLUFF LAKE TAILINGS AREAS

MONTH	MEAN TEMP (°C)	ADJ EVT (mm)	MEAN PRECIP. (mm)	NET WATER BALANCE (mm)
January	-26.2	0.0	18.0	18.0
February	-20.1	0.0	15.3	15.3
March	-14.4	0.0	16.2	16.2
April	-2.1	0.0	19.7	19.7
May	7.0	62.4	23.5	-38.9
June	13.3	112.4	42.4	-70.0
July	15.9	126.3	67.3	-59.0
August	14.5	103.5	52.1	-51.4
September	7.7	50.5	44.9	-5.6
October	1.1	8.4	30.3	21.9
November	-11.0	0.0	24.3	24.3
December	-20.8	0.0	25.4	25.4
TOTAL	-2.9	463.5	379.4	-84.1

TOTAL PRECIPITATION	379 mm
POTENTIAL EVAPOTRANSPIRATION	463 mm
NET WATER BALANCE	-84 mm

(from Clifton Associates Ltd., 1985)

TABLE I.2.B-2

AVERAGE WATER BUDGET CALCULATION
FOR KEY LAKE TAILINGS AREA

MONTH	MEAN TEMP (°C)	ADJ EVT (mm)	MEAN PRECIP. (mm)	NET WATER BALANCE (mm)
January	-25.1	0.0	14.8	14.8
February	-19.7	0.0	13.4	13.4
March	-13.6	0.0	15.6	15.6
April	-1.8	0.0	21.7	21.7
May	6.1	56.7	25.8	-30.9
June	12.9	109.3	50.8	-58.5
July	15.6	124.5	79.1	-45.4
August	14.4	104.2	60.5	-43.7
September	7.9	52.6	57.3	4.7
October	1.6	11.9	30.1	18.2
November	-10.4	0.0	20.9	20.9
December	-20.1	0.0	23.8	23.8
TOTAL	-2.7	459.2	413.8	-45.4

TOTAL PRECIPITATION	414 mm
POTENTIAL EVAPOTRANSPIRATION	459 mm
NET WATER BALANCE	-45 mm

(from Clifton Associates Ltd., 1985)

TABLE I.2.B-3

AVERAGE WATER BUDGET CALCULATION
FOR RABBIT LAKE TAILINGS AREA

MONTH	MEAN TEMP (°C)	ADJ EVT (mm)	MEAN PRECIP. (mm)	NET WATER BALANCE (mm)
January	-28.4	0.0	17.9	17.9
February	-23.5	0.0	13.7	13.7
March	-16.8	0.0	18.1	18.1
April	-4.4	0.0	19.1	19.1
May	4.7	48.7	27.3	-21.4
June	11.8	105.3	50.9	-54.4
July	15.5	126.7	64.0	-62.7
August	13.8	102.7	55.8	-46.9
September	6.7	48.2	51.0	2.8
October	-0.1	0.0	33.2	33.2
November	-13.0	0.0	27.4	27.4
December	-22.6	0.0	23.4	23.4
TOTAL	-4.7	431.6	401.8	-29.8

TOTAL PRECIPITATION	402 mm
POTENTIAL EVAPOTRANSPIRATION	432 mm
NET WATER BALANCE	-30 mm

(from Clifton Associates Ltd., 1985)

TABLE I.2.B-4

EXTREME AND MEAN PRECIPITATION EVENTS DERIVED FOR URANIUM CITY

	RETURN PERIOD		
	1:5 YEAR	1:25 YEAR	1:100 YEAR
FLOOD			
Rain (24 hr) mm	35.5	63.5	76.2
Snow (24 hr) cm	38.1	58.0	75.7
DROUGHT			
Minimum (annual) mm	300	257	231
Extreme (annual) mm	295	221	160
MEAN			
Total precipitation (annual) mm	354.1*		

*based on 10 to 14 years at Uranium City

(from Whiting et al, 1982)

storm of 305 mm in 12 hours at East Trout Lake. Based on this record and extrapolation by Gray (1970) it appears the PMP should be in the range of 300 mm in 24 hours. The water budgets plotted for the three reference weather stations indicate that evaporation will exceed precipitation by approximately 30 to 84 mm per year; however, the variation in the annual water budget can be considerable.

I.2.3.A FLORA, ONTARIO

The climatic vegetation of the Elliot Lake region is mixed deciduous and conifer forest classified as Great Lakes - St. Lawrence Forest Region (Rowe, 1971). The forest region is of a very mixed nature, characterized by eastern, red and white pines, eastern hemlock and yellow birch along with maple, oak and basswood (Murray, 1977). Forest species, typical of the more northern Boreal Forest Region (Rowe, 1971), such as white and black spruces, balsam fir, jack pine, trembling aspen, balsam, poplar and white birch are intermixed.

Kalin, 1983, surveyed inactive uranium mill tailings disposal sites in the Elliot Lake region, describing their surface characteristics, identifying naturally invading plant species and determining chemical and physical characteristics of the tailings. In the wet areas of most sites, wetland vegetation communities were recorded which were dominated by species of cattails (Typhaceae) along with some species of rushes (Juneaceue) and sedges (Cyperaceae). Dry areas of the tailings exhibited a variety of surface vegetative features which were a reflection of different reclamation procedures undertaken at various sites. Most of the indigenous species of vascular plants identified on dry areas of the tailings occurred only sporadically. Invading plants found on most sites were the tree species trembling aspen and paper birch. Coniferous species were notable by their absence (except where experimentally planted).

I.2.3.B FLORA, SASKATCHEWAN

The vegetation in the uranium mining area is a typical softwood forest consisting of jackpine, black spruce and tamarack as the principal species in the area. White spruce, white birch and some balsam fir are also found. Trembling aspen becomes increasingly rarer farther north. The size of the forest and growth rates also decrease with increasing latitude.

The lowland areas are covered with peat in the forms of bogs and fens. Various shrubs, particularly alder and willow, are common. These species are typical of wetlands in a northern coniferous forest in a discontinuous permafrost zone.

Forest fire control is not well established over much of the mining area. Large areas have been burned in fires of various ages. For instance, the Key Lake, Rabbit Lake and Cluff Lake mines are in areas that have been extensively burned.

I.2.4.A FAUNA, ONTARIO

Work carried out by J.F. MacLaren, 1978b, indicated moose, white-tailed deer and red fox cross non-operating tailings frequently but seem to avoid

operating areas. Gulls and ravens were found on most tailings areas and waterfowl were frequently seen in tailings ponds.

The Ministry of Natural Resources reported heron rookeries, bald eagles and osprey in the area but no specific locations have been identified.

I.2.4.B FAUNA, SASKATCHEWAN

The wildlife of northern Saskatchewan is controlled by the habitat. Large mammals such as moose, deer, wolf, bear and caribou are present along with smaller fur bearers including mink, squirrel, muskrat, weasel, beaver, martin, otter, fox and linx. Birds include spruce grouse, ptarmigan, eagles, ravens and, depending upon the season, migratory water fowl and other migratory species.

I.2.5.A LAND USE, ONTARIO

Elliot Lake is a town of approximately 17,000 people (Statistics Canada, 1986). The tailings management areas are all within a 20 km radius of the town. The closest tailings sites are within 2 km of town and/or permanent residences.

The land use designation of the Elliot Lake area is extremely broad including mining, recreational and tourism. However, the land use intent of the area, as designated by the Ministry of Natural Resources, is initially for mineral exploration and extraction. The area is restricted to approved mining and municipal uses. From the Ministry's perspective, fishery management will be undertaken to enhance the angling quality of the smaller lakes in the region through a fish stocking program (Jewett, 1986).

1.2.5.B LAND USE, SASKATCHEWAN

Most of the land is in a primitive state and land use has been only slightly altered from historic patterns. Hunting and fishing are exploited by northern residents. Tourism is popular, primarily related to hunting and freshwater sport fishing. Widely spaced transportation corridors and mineral extraction are the other primary land uses.

I.3.0 CHARACTERISTICS OF TAILINGS

I.3.1.A TYPE OF ORE, ONTARIO

The Elliot Lake ore zone is a detrital deposit occurring within a uraniferous pyritic quartz-pebble conglomerate. The predominant uranium bearing minerals, brannerite and uraninite, monazite and uranothorite, are present as microscopic particles around the pyrite and quartz-pebbles.

The approximate percentage composition of the conglomerate ore is given in Table I.3.A-1. The specific values will vary between mines. However, the values listed are averages determined from expected ranges of the elements. La Rocque and Pakkala, 1978, report the specific gravity of the ore to be 2.75. In general the uranium grade of the ore in the Elliot Lake area is 0.5 to 1.5 kg/tonne (Golder, 1984).

I.3.1.B TYPE OF ORE, SASKATCHEWAN

The character of the ore encountered in the northern Saskatchewan mines varies considerably. The mineralogy of the deposits is discussed below.

i) Cluff Lake

The Cluff Lake mill will be supplied with ore originating from several ore bodies. Melis (1985) reported that the Cluff Lake ore "is considered to be a relatively clean ore by northern Saskatchewan standards since there is no arsenic or nickel minerals associated with the pitchblende uranium mineralization".

A typical mill feed analysis of the Cluff Lake Phase II ore is given in Table I.3.B-1.

ii) Gunnar

The Gunnar ore was relatively clean pitchblende. The ore contained 0.175% U308 in the form of pitchblende and uranophane in a syenite containing about 8% calcite and 2 to 3% hematite.

iii) Key Lake

Melis (1985) describes the Key Lake uranium ore minerals as being "euhedral and radially textured pitchblende, sooty pitchblende and smaller amounts of coffinite." The uranium mineralization is associated with nickel arsenides. Extensive intergrowth of the uranium and nickel minerals is present. A typical analysis of the Key Lake ore is given in Table I.3.B-2.

iv) Lorado

The Lorado mill operated for only a short period of time, processing approximately 545,000 tonnes of ore with an average grading of 0.24 percent U308. According to Whiting et al, (1982) the main suppliers for the Lorado custom mill were the Lorado, Cayzor, Rix Leonard and Cinch Lake ore bodies. The uranium minerals in all of these ore bodies were pitchblende with minor

TABLE I.3.A-1

TYPICAL ANALYSIS OF ELLIOT LAKE URANIUM ORE

Element	Percent (except where noted)	Element	Percent
U3O8	0.1	Mn	0.004
Th	0.04	Cr	<0.001
Ra	11 Bq/g	Ba	0.02
L.O.I.	3	Cd	<0.001
SiO2	80	Sb	<0.001
Fe	3-5	Sn	<0.001
S	2-4	B	0.004
Cu	0.007	As	<0.005
Zn	0.005	Ca	0.1
Pb	0.04	Mg	0.2
Mo	<0.001	Na	0.1
V	<0.001	K	2
Ni	0.003	F	0.02
Co	0.005	SO4	<0.10
Ti	0.08	PO4	0.1-0.2
Al	3-4	CO2	0.2
Bi	<0.001	Cl-Br-I	0.005
Ag	<0.002	NH3	0.02

TABLE I.3.B-1

TYPICAL ANALYSIS OF CLUFF LAKE PHASE II ORE

Element	% (except where noted)
U_3O_8	0.35-0.7
Th	0.0006
Ra-226	18 Bq/g
Pb-210	17 Bq/g
Th-230	20 Bq/g
Si	33.1
Fe	1.5
S	0.03
Cu	0.008
Zn	0.007
Pb	0.015
Mo	0.02
V	0.02
Ni	0.003
Ti	0.015
Al	5.6
Bi	0.002
Ba	0.002
B	0.007
As	0.001
Ca	0.15
Mg	1.56
Na	0.06
K	1.3
P	0.04
CO_3	0.04
Cl	0.001
Total C	0.01

(from Cluff Mining, 1982)

TABLE I.3.B-2

TYPICAL ANALYSIS OF KEY LAKE ORE

Element	Gaertner Ore (%, except where noted)	Deilmann Ore
U_3O_8	2	2.9
Ra-226	220 Bq/g	N/A
SiO_2	50	50
Fe	3.5	3
S	1	0.8
Cu	0.03	0.09
Zn	0.08	0.03
Mo	0.006	0.03
V	0.08	0.09
Ni	2.5	1.1
Co	0.08	0.08
Ti	0.4	0.6
Al	9	10.3
As	1.5	1.1
Ca	0.4	0.4
Mg	3	2.9
Na	0.7	0.9
K	0.6	1.5
F	0.05	N/A
P_2O_5	0.16	0.15
CO_2	1	0.8
Cl	0.05	N/A

(from Melis Consulting Engineers Ltd., 1985)

yellow oxides. The gangue minerals were feldspar, quartz, pyrite, calcite and hematite. The Lorado ore contained up to 15% sulfides while the remainder had about 1% sulfide.

v) Rabbit Lake and Collins Bay

The Rabbit Lake ore body consisted of primarily pitchblende and coffinite with minor nickel and arsenic content. Calcite and phyllosilicates are the most common gangue minerals.

The Collins Bay B-Zone ore body is also primarily pitchblende and coffinite but has a much higher content of arsenic and nickel. Typical analyses for the Rabbit Lake and Collins Bay ores are given in Table I.3.B-3.

I.3.2.A EXTRACTION PROCESSES AND TAILINGS CONDITIONING, ONTARIO

The uranium ore extraction process and tailings conditioning are and have been essentially the same for each of the mills in the area, specifically; a sulfuric acid-leach extraction process and lime neutralization of the tailings. Feenstra et al, 1981, reports during the 1950s and 1960s neutralization of the tailings was only to pH 6 to 7. Current practice is to neutralize the tailings to pH 8 to 11 prior to deposition into the various impoundments (Vivyurka, 1986 and Laliberte, 1985). Details of the extraction processes and tailings neutralization for the four current mills, as described by Melis, 1985, except where noted, are outlined below.

i) Denison Mine

The Denison uranium mine has been in continuous operation since 1957 with the mill capacity increasing in stages through the years to the present design capacity of approximately 13,000 tonnes per day.

The milling circuit is generally typical of Elliot Lake uranium operations. Ground ore from the semi-autogenous grinding (SAG) plant which was installed in 1979, is leached in pachucas (air-agitated tanks) with sulphuric acid at elevated temperature (about 80°C) and ambient pressure. The uranium-rich solution in the leach pulp is separated by thickening (wash thickeners) and filtration (drum filters). The uranium is then recovered from solution by ion exchange and a concentrated eluate is produced by nitric acid elution of the loaded resin. Uranium in the concentrated eluate is precipitated with ammonia at pH 7 to produce yellowcake (ammonium diuranate) which is dewatered, dried and packaged in drums for shipment.

Additional uranium is recovered from the Denison operation by bacterial leaching of mined-out or low-grade stopes underground. The acidic mine water which contains around 0.1 kg U_3O_8 per tonne of solution (LaRocque, 1982) is pumped to the mill where it is neutralized with lime to pH 9 to 10 and the precipitate slurry dewatered in a thickener. The uranium-rich precipitate is then re-dissolved and recycled to the ion exchange circuit for recovery of the uranium. The clarified mine water from this operation is used as mill process water.

TABLE I.3.B-3

TYPICAL ANALYSIS OF RABBIT LAKE AND COLLINS BAY B-ZONE ORES

Element	Rabbit Lake Ore (%)	Collins Bay B-Zone Ore (%)
U308	0.3	0.6
ThO2	n/a	0.003-0.04
Fe	n/a	1-3
S	n/a	0.1
Mo	0.002	0.01-0.02
V	0.02	0.02-0.05
Ni	0.01	0.4
As	0.003	0.5
PO4	0.2	0.02
CO2	2-3	0.2
Ra-226(est.)	30 Bq/g	60 Bq/g

(from Melis Consulting Engineers Ltd., 1985)

Tailings slurry from the mill is bulk neutralized with lime to pH 10 to 11 and pumped to the Denison Long Lake tailings basin via a 0.5 m diameter polyethylene line or to the backfill cyclone plant.

ii) Quirke Mine

The Quirke mine and mill was operated from 1956 to 1961 and then re-started again in 1968. The present mill throughput is 6,400 tonnes per day.

The milling circuit is similar to the Denison operation with the only difference being in the liquid/solid separation process where the uranium solution is separated from the leach slurry by wash cyclones and counter-current decantation in six-stages of thickeners. Yellowcake is produced by precipitation of ion exchange eluate with ammonia. Uranium recovery from mine water is achieved by precipitation of acidic mine water with lime.

Tailings slurry, which exists at pH 2 to 2.5, is neutralized with limestone to pH 3.5 and lime to pH 10 to 11 in a series of five tailings neutralization pachucas.

The neutralized slurry is pumped to the Quirke Mine tailings basin.

iii) Panel Mine

The Panel operation was active from 1958 to 1961 and was re-activated again in 1979. The mill throughput capacity is 3,000 tonnes per day.

The milling process is the same as the Denison operation except in the ion exchange circuit, where loaded resin is eluted with 10% sulphuric acid and uranium is precipitated with magnesium hydroxide. As with the other Elliot Lake operations, uranium is recovered from mine water by precipitation with lime.

Tailings slurry is bulk neutralized with limestone and lime and pumped to the Panel Lake tailings management area.

iv) Stanleigh Mine

The Stanleigh mine and mill was operated from 1958 to 1960 and recently went back into production in mid-1983.

The Stanleigh mill circuit, with a capacity of 4,500 tonnes per day, is very similar to the Panel operation except in the type of equipment used for processing. Grinding of the ore is accomplished in a semi-autogenous grinding mill as opposed to conventional rod-pebble mill grinding used at Panel. Liquid-solid separation is carried out using horizontal belt filters. Continuous moving bed ion exchange is used to recover uranium from solution. Magnesia precipitation of uranium is practiced.

Tailings slurry is bulk-neutralized with limestone and lime and pumped to the Stanleigh Mine Tailings Impoundment area where the neutralized tailings are deposited over old tailings from the previous Stanleigh and Milliken operations.

I.3.2.B EXTRACTION PROCESSES AND TAILINGS CONDITIONING, SASKATCHEWAN

Uranium extraction processes varied considerably from mill to mill, depending upon the mineralogy of the ore.

i) Cluff Lake

The Cluff Lake Phase I operation started in 1981. It mined approximately 54,000 tonnes of high grade ore from the D ore body yielding approximately 3,600 tonnes of uranium. The milling process consisted of gravity concentration, acid leaching, and direct precipitation of the leach liquor with magnesia. The waste stream included leach residues which are presently contained in concrete vaults stored under cover on site, and neutralized waste solutions containing a minimal amount of precipitates.

Melis (1985) reported that the Phase I mill was modified in 1984 to accept lower grade ore from other Cluff Lake area ore bodies. The Phase II mill has a capacity of 230,000 tonnes per year and utilizes conventional grinding (to minus 420 microns) and sulfuric acid leaching of ore. The tailings slurry from mill are neutralized with lime and pumped to the waste management area where the tailings decant water is treated with barium chloride, lime and coagulant. It is clarified and filtered prior to discharge.

ii) Gunnar

The Gunnar mill operated from 1954 to 1964 using a conventional sulfuric acid-sodium chlorate circuit with ion exchange for uranium recovery. The ore was ground to 50 percent finer than the No. 200 sieve. No conditioning was applied to the tailings. They were disposed of at about 30 percent density.

iii) Key Lake

The Key Lake mill has a capacity of approximately 720 tonnes per day. The process consists of semi-autogenous grinding and two stage leaching with sulfuric acid. The circuit provides for solvent extraction for uranium recovery and purification. Uranium is precipitated with ammonia and an ammonium sulphate crystallization plant removes ammonia which is marketed as a fertilizer grade material. The leach tailings are neutralized with lime to pH 11 or greater and liquid waste streams are neutralized in a separate waste treatment circuit. The neutralized tailings are thickened and discharged to the tailings pond. Liquid effluents are treated with barium chloride and lime and clarified and the pH adjusted, if necessary, prior to discharge to the environment.

iv) Lorado

Whiting et al, (1982) reports that the Lorado mill was designed to process 635 tonnes of ore per day. The ore was crushed and ground to 60 percent passing the No. 200 sieve and leached with sulfuric acid. The tailings were not conditioned and were discharged at approximately pH 2 directly to Nero Lake.

v) Rabbit Lake

The Rabbit Lake mill utilized an acid leach circuit, CCD thickeners and solvent extraction followed by ammonia precipitation to process the Rabbit Lake ore body. The tailings are neutralized and discharged to a tailings basin. The liquid decant was treated with barium chloride and clarified in settling ponds and sand filters prior to discharge to the environment.

vi) Collins Bay B-Zone

The Rabbit Lake mill was modified to allow processing of the B-Zone ores. GMCL (1982) report that the major modifications relate to replacement of ammonia in the solvent extraction and uranium precipitation circuits. The mill tailings will be neutralized and filtered prior to placement in the Rabbit Lake pit. The liquid effluents will be treated separately for removal of radium and heavy metal contaminants. Waste precipitates will be discharged to the tailings area with the filtered tailings.

I.3.3.A PHYSICAL PROPERTIES OF TAILINGS, ONTARIO

A summary of the physical properties of the non-cohesive sand tailings and low plasticity silt tailings in the Elliot Lake area are noted in Table I.3.A-2. Gradation ranges for the sand, silt and cycloned tailings are shown on Figure I.3.A-1. These data represent ranges in values from the following reports or publications:

Dave et al, 1981
Dubrovsky et al, 1985
H.Q. Golder, 1972
1974
1978c, e
1979
1980a
Golder, 1981e, g, i, l
1982a, b
Matyas et al, 1984
Reades et al, 1981

Figure I.3.A-2, shows the variation in natural water content, total and dry unit weights, in situ vertical stresses and undrained shear strength against the depth of the tailings below ground surface. Golder, 1984, noted the natural water content of the fine tailings decreases noticeably with depth while the coarser tailings demonstrate only a slight decrease in water content. Unit weights and in situ vertical effective stresses tend to increase with depth in a similar fashion for both fine and coarse tailings. Undrained shear strength in the tailings deposit increased with depth to a relatively constant value of about 15 kiloPascals below a depth of about 4 metres.

Matyas et al, 1984, reports the Elliot Lake uranium tailings are normally consolidated with a hydrostatic distribution of pore pressures. Excess pore pressures due to the accretion of tailings dissipate quickly in the coarse tailings but some excess pore pressures have been recorded in the silt tailings where the rate of accretion has been about 1.5 m/year.

TABLE I.3.A-2

PHYSICAL PROPERTIES OF ELLIOT LAKE TAILINGS

PHYSICAL PROPERTIES		COARSE TAILINGS (SANDS)	FINE TAILINGS (SLIMES)
GRADATION (% by weight)	GRAVEL	0-15%	0%
	SAND	55-85%	0-45%
	SILT	0-40%	55-85%
	CLAY	0-5%	0-15%
SATURATED UNIT WEIGHT		19.5-21.2 kN/m^3	16.5-21.7 kN/m^3
SPECIFIC GRAVITY		2.73-2.78	2.59-2.81
VOID RATIO		.55-.85	1.3-2
IN SITU WATER CONTENT		22-35%	40-80%
ATTERBERG LIMITS	Liquid Limit	N/A	25-40%
	Plasticity Index	N/A	0-10%
COMPACTION CHARACTERISTICS (STANDARD PROCTOR)	Water Content	10-15.6%	N/A
	Dry unit weight	16.5-17.3 kN/m^3	N/A
EFFECTIVE SHEAR STRENGTH			
Angle of Internal Friction		30.5-41 degrees	20-46 degrees
Cohesion		0 kPa	0 kPa
DYNAMIC STRENGTH Kc=1 (cyclic stress for failure at 6 cycles)		0.35	0.27
HYDRAULIC CONDUCTIVITY (m/s)		10^{-4} to 10^{-6}	10^{-6} to 10^{-9}
CONSOLIDATION CHARACTERISTICS			
Compression Index		0.04-0.1	0.20-0.45
Coefficient of Consolidation		0.2-0.05 cm^2/s	0.002-0.0005 cm^2/s

PARTICLE SIZE DISTRIBUTION

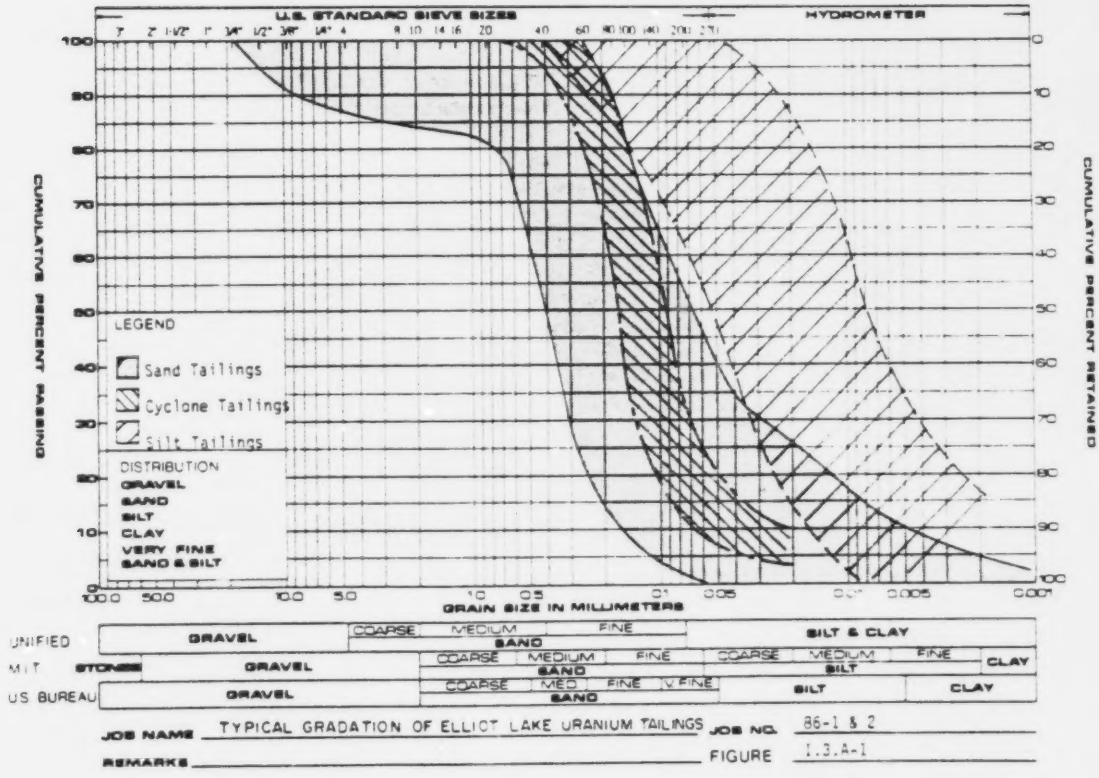
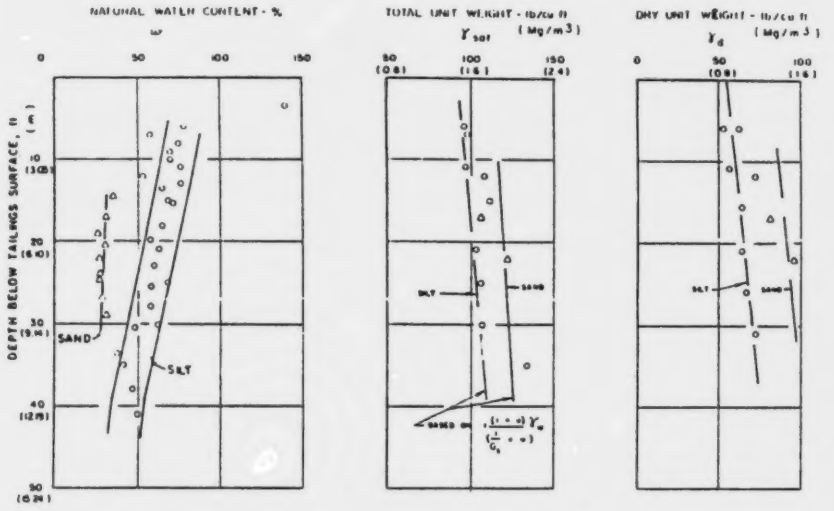


FIGURE I.3.A-1 TYPICAL GRADATION OF ELLIOT LAKE URANIUM TAILINGS



(After Golder, 1984)

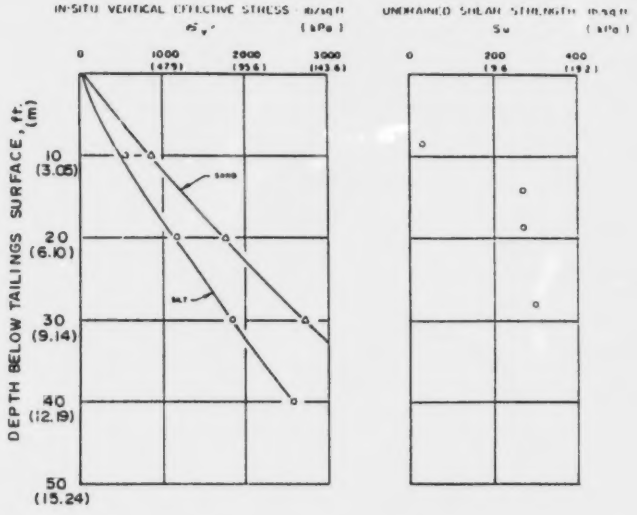


FIGURE I.3.A-2

VARIATION OF PHYSICAL PROPERTIES TYPICAL OF ELLIOT LAKE TAILINGS WITH DEPTH

As indicated in Table I.3.A-2, the hydraulic conductivity of the tailings is extremely variable. The actual value is dependent on the void ratio and gradation of the material.

The angle of internal friction for the tailings material is generally high. However, it too was found to be variable depending on the initial void ratio. The friction angle for silt was found to be higher than that of sand. Matyas et al, 1984, reports this is attributed to the higher percentage of needle-shaped particles in the silt.

I.3.3.B PHYSICAL PROPERTIES OF TAILINGS, SASKATCHEWAN

The physical properties of tailings deposited at the major tailings management areas in Saskatchewan are summarized in Tables I.3.B-4 to I.3.B-8 inclusive.

I.3.4.A CHEMICAL PROPERTIES OF TAILINGS, ONTARIO

The chemical properties of uranium tailings in the Elliot Lake area have been thoroughly studied by Golder Associates, Canmet, and the University of Waterloo (Golder, 1981g, 1981h; Cherry et al, 1980; Dave et al, 1981; 1982; Dubrovsky, 1985; and Feenstra et al, 1981).

Typical chemical characteristics for both neutralized and oxidized tailings pore water are presented in Table I.3.A-3. Work reported by Feenstra et al, 1981, indicate oxidation of tailings generally takes place in the upper 3 to 4.5 m of the tailings surface. Below this depth, the tailings pore water is almost the same chemistry as the discharge from the mill.

In areas where the ground water flow is downward, acidic water produced in the unsaturated zone moves downward replacing the neutralized tailings water and may eventually turn all of the tailings pore water acidic (Cherry et al, 1980).

I.3.4.B CHEMICAL PROPERTIES OF TAILINGS, SASKATCHEWAN

Chemical properties of Key Lake tailings solids are representative of typical Saskatchewan mill tailings solids and are therefore summarized in Table I.3.B-9. Chemical properties of liquids for various sites are given in Tables I.3.B-10 to I.3.B-14 inclusive. Chemical analyses of pore water recovered from existing tailings deposits are given in Tables I.3.B-15 to I.3.B-17 inclusive.

TABLE I.3.B-4

PHYSICAL PROPERTIES OF CLUFF LAKE TAILINGS

	TAILINGS PILE	SLIMES
WATER CONTENT (%)	21.0-24.9	217.6-359.5
SPECIFIC GRAVITY	2.74-2.76	2.82-3.28*
D10 (mm)	0.15	-
D30 (mm)	0.25	-
D60 (mm)	0.43	-
COEFFICIENT OF UNIFORMITY	2.9	-
GRAVEL (% by weight)	0	-
SAND (% by weight)	98	2
SILT AND CLAY (% by weight)	2	98
LIQUID LIMIT (%)	NP	97.8-105.0
PLASTICITY INDEX (%)	NP	13.7-27.4
PERMEABILITY (m/s)	$4.2\text{-}9.1 \times 10^{-5}$	$0.6\text{-}3.4 \times 10^{-8}$
COMPRESSION INDEX	0.063-0.49	-

*value questioned by the investigator

(from The Geotechnical Group, 1985; Golder Associates Ltd., 1983)

TABLE I.3.B-5

PHYSICAL PROPERTIES OF GUNNAR TAILINGS

	GUNNAR MAIN	GUNNAR CENTRAL	LANGLEY BAY
WATER CONTENT (%)	3.6-77.6	16.5-39.4	6.8-86.3
SPECIFIC GRAVITY	2.60-2.78	2.70-2.73	2.73-2.85
DRY DENSITY (Mg/m3)	0.90-1.75	1.23-1.63	0.97-1.40
D10 (mm)	<0.001-0.10	<0.001-0.01	<0.001-0.009
COEFFICIENT OF UNIFORMITY	4 - 7.5	-	-
GRAVEL (% by weight)	-	-	-
SAND (% by weight)	88.2-92.0	85.0	35.0
SILT (% by weight)	6.2-9.7	10.9	60.8
CLAY (% by weight)	1.8-2.1	4.1	4.2
LIQUID LIMIT (%)	NP-46.1	NP-40.1	NP-60.7
PLASTICITY INDEX (%)	0.8-19.1	1.7-17.4	5.0-20.6
PERMEABILITY (m/s)	5.7×10^{-12} to 1.8×10^{-5}	3.1 to 3.4×10^{-6}	- -
COMPRESSION INDEX	0.05	-	-

(from Redmann and Frankling, 1982; Swanson and Abouguendia, 1981)
BBT Geotechnical Consultants, no date

TABLE I.3.B-6

PHYSICAL PROPERTIES OF KEY LAKE TAILINGS

WATER CONTENT (%)	119.0-216.7
SPECIFIC GRAVITY	2.90-2.99
VOID RATIO	4.6-5.6 (est)
DRY DENSITY (Mg/m^3)	0.39-0.66
D10 (mm)	<0.075
D30 (mm)	<0.075
D60 (mm)	<0.075
SAND (% by weight)	15-25
SILT AND CLAY (% by weight)	75-85
PERMEABILITY (m/s)	
(oedometer test)	$0.1\text{-}2.8 \times 10^{-8}$
(permeameter)	$1.1\text{-}1.4 \times 10^{-7}$
COMPRESSION INDEX	1.53-2.09
COEF. OF COMPRESSIBILITY (m^2/y)	15.47-102.00*

* lower value for stress range 422 to 816 kPa,
higher value for stress range 495 to 1017 kPa

(from Knight and Piesold Ltd., 1985)

TABLE I.3.B-7

PHYSICAL PROPERTIES OF LORADO TAILINGS

	SILTY	SANDY
WATER CONTENT (%)	5.0-39.5	
DRY DENSITY (Mg/m^3)	1.60-1.76	
D10 (mm)	0.016	-
D30 (mm)	0.06	-
D60 (mm)	0.14	0.007
COEFFICIENT OF UNIFORMITY	8.8	-
SAND (% by weight)	65	2
SILT AND CLAY (% by weight)	35	98
PERMEABILITY (m/s)	2×10^{-6}	2×10^{-5}

(from Swanson and Abouguendia, 1981; Whiting et al, 1982)

TABLE I.3.B-8

PHYSICAL PROPERTIES OF RABBIT LAKE TAILINGS

WATER CONTENT (%)	87.6-100.7
SPECIFIC GRAVITY	2.83-2.90
VOID RATIO	2.4**
DRY DENSITY (Mg/m^3)	0.63-0.81
D10 (mm)	0.0055-0.01
D30 (mm)	0.0075-0.03
D60 (mm)	0.0075-0.08
COEFFICIENT OF UNIFORMITY	1.5-6.7
SAND (% by weight)	1-57
SILT AND CLAY (% by weight)	39-100
PERMEABILITY (m/s)	$0.09\text{-}2.0 \times 10^{-5}$
COMPRESSION INDEX	0.76-1.71
COEF. OF COMPRESSIBILITY (m^2/y)	126 - 631*
EFFECTIVE COHESION (kPa)	13.8
FRICTION ANGLE (degrees)	35-37

* maximum pressure = 384 kPa
** consolidated tailings

(from Gulf Minerals Canada Ltd., 1981b, 1981c; MacLaren Engineers Inc., 1984)

TABLE I.3.A-3

CHEMICAL CHARACTERISTICS OF TAILINGS PORE WATER, ELLIOT LAKE AREA

ELEMENT	NEUTRALIZED TAILINGS (mg/L)	OXIDIZED TAILINGS (mg/L)
Total dissolved solids	3,000-5,000	10,000-40,000
Calcium	400-500	400-600
Iron	<1	3,000-15,000
Sulphate	1,000-2,000	5,000-25,000
Chloride	50-100	50-100
Ammonia	50-100	0-100
pH	8-10	2-6
Activity Ra226	600-1,500 pCi/L	10-220 pCi/L

(After Golder Associates Ltd., 1984)

TABLE I.3.B-9

CHEMICAL PROPERTIES OF TAILINGS SOLIDS, KEY LAKE

MINERAL/COMPOUND	(% by Weight)
MAJOR CONSTITUENTS	
QUARTZ	48
GYPSUM	26
GRAPHITE	2*
ILLITE, TRICHLORITE	7.4
ETTRINGITE	3.7
CALCIUM ARSENATE	2.0
CALCITE	5.0
GERSDORFFITE	0.8
NICKEL COMPOUNDS	2.0
IRON COMPOUNDS	3.2
MINOR CONSTITUENTS	
COBALT COMPOUNDS	0.1
URANIUM COMPOUNDS	<0.1
ZINC COMPOUNDS	<0.1
LEAD COMPOUNDS	<0.1
COPPER COMPOUNDS	<0.1
TRACE CONSTITUENTS	
PHOSPHATES	<0.01
V	<0.01
Ti	<0.01
Mn	<0.001
Cd	<0.001
Th	<0.001
Mo	<0.001
Y	<0.001
Ba	<0.001
Cr	<0.001
La	<0.001
Sr	<0.0001
Be	<0.0001
TOTAL	100.2%

* assumed, no measurements available

(from Knight and Piesold Ltd., 1985)

TABLE I.3.B-10

CHEMICAL PROPERTIES OF TAILINGS LIQUIDS, CLUFF LAKE

	MILL EFFLUENT	TAILINGS POND	STS DISCHARGE	TOE DRAINAGE
Time	1984	1984	1984	1984
pH	8.62	7.35	7.48	6.45
Cond	9406	4645	4537	3096.7
T.P04			0.05	
TKN	20.1	2.45	2.40	
NH3	29	0.10	1.27	
N03	0.06	0.51	1.03	
TSS	262.4	10.5	9.4	14.8
S04	2762	1667.5	1590	1305.8
CL	1714.4	794.8	784	358.7
HC03	230.2	97	82	137.8
C03	831	NIL	NIL	NIL
Ca	1319.4	403.5	413	283
Na	180.4	611.3	572	215.2
Mg	25.2	136	131	198.5
K		7.8	7.4	5.4
D. Ra226	534 Bq/L	8.0 Bq/L	0.21 Bq/L	0.03 Bq/L
U	3.15	3.775	2.901	0.0036
Pb210	35 Bq/L	1.2 Bq/L	0.40 Bq/L	<0.02 Bq/L
Po210	6.8 Bq/L	0.14 Bq/L	0.14 Bq/L	0.02 Bq/L
Th230	24 Bq/L	0.19 Bq/L	0.05 Bq/L	<0.02 Bq/L
Ag			0.001	
Al			0.068	
As	0.016	0.0015	1.3	<0.0005
B	0.70	0.40	0.41	0.09
Ba	0.07	0.041	0.15	0.042
Cd	0.0005	0.0005	0.0007	>0.0005
Co	0.009	0.003	0.002	0.024
Cr	0.025	0.015	0.010	0.008
Cu	0.029	0.02	0.003	<0.001
Fe	2.2	2.1	0.37	6.8
Hg	0.00005	0.00007	<0.00007	<0.00005
Mn	0.35	0.49	0.256	4.2
Mo	3.0	0.57	0.61	0.012
Ni	0.116	0.017	0.053	0.007
Pb	0.016	0.007	0.005	<0.005
V	0.18	0.05	0.04	0.03
Zn	0.07	0.0008	0.032	1.5

Note: pH is reported in standard units; all other parameters are in mg/L except where noted.

(from Amok Ltd., 1985 from sampling carried out in 1984)

TABLE I.3.B-11

CHEMICAL PROPERTIES OF TAILINGS LIQUIDS, GUNNAR

NO DATA

TABLE I.3.B-12

CHEMICAL PROPERTIES OF TAILINGS LIQUIDS, KEY LAKE

	INCOMING TAILINGS	TAILINGS EFFLUENT	TAILINGS SEEPAGE
pH	6.4-12.1	11.3-11.5	7.1-7.4
Cond	3130-6810	3180	2030
NH3	11-33		34
NO3	0.01-0.06		0.03
SO4	1310-3450	1590-1720	1150-1470
Cl	14-387		16
Ca	520-1050	655-780	374-550
Na	15-210	23-92	24-47
Mg	0.1-510	<0.16	0.63-3.9
K	4.9-30.0	7.8-17	7.8-8.9
D. Ra226	25-420 Bq/L	210 Bq/L	10-45 Bq/L
U	0.004-0.1	3.2-13	0.04-0.13
Pb210	0.4-45 Bq/L	3.0 Bq/L	0.07-0.45 Bq/L
Po210	0.5 Bq/L	2.0 Bq/L	0.2-1.4 Bq/L
Th230	0.5-4.5 Bq/L		
Ag	<0.001	<0.002	<0.001
Al	0-0.15	0.22-0.47	0-6.1
As	0.8-4.6		0.062-0.076
B	0.02-0.52	0.09-0.27	0.02-0.04
Ba	0.01-0.12	0.049-0.052	0.04-0.061
Be	<0.001	<0.001	<0.001
Cd	0-0.004	0.001-0.009	0-0.01
Co	<0.001	<0.001	0-0.009
Cr	0.008-0.024	0.011-0.022	0.004-0.014
Cu	0.005-0.009	0.006-0.008	0.007-0.009
Fe	0.032-0.064	0.046-0.049	0.042-3.8
Mn	0-1.9	<0.001	0.057-4.2
Mo	0.-3.7	0.58-1.3	0.48-0.85
Ni	0.01-0.29	0.005-0.011	0.0411-0.094
P	0.050-0.38	0.07-0.2	0.05-0.08
Pb	0-0.28	<0.005-0.02	0-0.02
Sb	0-0.002		0.002
Se	0.001-0.02		<0.001
Si	0.2-0.8		1.3
Ti	<0.001	<0.001	<0.001
V	0.06-0.21	0.06-0.14	0-0.07
W	0-1.1	0.45-0.89	0.06-0.31
Zn	0.002-0.47	0.001	0.06-0.21
Zr	<0.001		<0.001

Note: pH is reported in standard units; all other parameters are in mg/L except where noted.

(from Knight and Piesold Ltd., 1985)

TABLE I.3.B-13

CHEMICAL PROPERTIES OF TAILINGS LIQUIDS, LORADO

pH	3.13
Cond	4990
T.PO4	0.27
TSS	12.9
SO4	3690
Cl	99
CO3	nil
Ca	433
Na	26
Mg	203
K	11
D. Ra226	20 Bq/L
T. Ra226	10.84 Bq/L
U	.305
Po210	20 Bq/L
Th230	<0.01 Bq/L
Ag	160
B	0.17
Ba	0.013
Bi	0.058
Cd	<0.0005
Co	0.48
Cr	0.086
Cu	<0.001
Fe	540
Hg	<0.00005
Mn	21
Mo	0.10
Ni	0.95
Pb	<0.002
St	<0.001
V	0.61
Zn	0.85

Note: pH is reported in standard units; all other parameters are in mg/L except where noted.

(from Whiting et al, 1982)

TABLE I.3.B-14

CHEMICAL PROPERTIES OF TAILINGS LIQUIDS, RABBIT LAKE

	TAILINGS POND BARGE PUMP	PRECIPITATION POND OUTFLOW	EFFLUENT STREAM
pH	7.86	6.96	6.01
Cond	8941	8754	1936
T.PO4		0.04	0.02
TKN		213	36.18
NH3		200	31.44
NO3			0.95
TSS	12.9	13.6	2.9
ETHER SOL		1.2	
SO4		6542	1186
CL		163	24
HCO3		47	16
CO3		1	1
Ca		428	82.1
Na		100	27.22
Mg		1171	2277
K		23.1	4.89
D. Ra226		0.016	
T. Ra226	10.84	0.352	0.018
U	513	633	32.7
Pb210		0.12	0.25
Th230	0.137	0.243	0.006
Ag	<.004	0.015	<0.001
As	4	13	15
B	0.45	1.06	0.06
Ba	0.049	0.144	0.116
Cd	<0.003	0.004	0.007
Co	0.01	<0.04	<0.003
Cr	0.018	0.027	0.023
Cu	0.02	0.038	0.023
F	8.5	8	0.57
Fe	0.142	0.756	0.832
Hg	0.08	0.08	0.68
Mn	1.52	2.41	0.556
Mo	1.48	1.4	0.31
Ni	0.06	0.082	0.05
Pb	<0.03	0.05	0.033
St	0.07	0.03	<0.001
V	<0.01	0.11	<0.01
Zn	0.07	0.027	0.024

Note: pH is reported in standard units; all other parameters are in mg/L except where noted.

(from Eldorado Resources Limited, 1984)

TABLE I.3.B-15

PORE WATER CHEMISTRY, GUNNAR

	GUNNAR MAIN	OUTLET GUNNAR MAIN	GUNNAR CENTRAL	LANGLEY BAY
Time	1984	1984	1984	1984
pH	7.6-7.9	4.1	3.9-4.9	4.1
Cond	4600-5600	8500-9000	4500-14,000	5,000
O-P04	1	1	1-10	1
N03	1	1	1-10	1
S04	2300-2700	4900-5600	2700-10,700	3100
CL	160-220	510-540	150-670	140
Ca	370-590	350-450	340-420	230-460
Na	107-185	260-330	94-440	61-87
Mg	380-680	780-1010	300-2240	200-330
K	4.3-24	15.4-25	8.9-18.7	4.2-6.4
D. Ra226	1.7-2.6 Bq/L	1.2-7.5 Bq/L		
U	.450-2.6	.043-0.12		
Pb210	<0.3-2.3 Bq/L	<1.0-6.5 Bq/L		
Po210	0.04-1.4 Bq/L	0.15-1.9 Bq/L		
Th230	<0.02-0.75 Bq/L	0.09-0.80 Bq/L		
Al	.27-.33	.45-.51	0.37-16.2	0.26-0.30
B	1	1	1-10	1
Ba	0.04-0.07	0.04-0.15		
Cd	0.020-0.050	0.02-0.12		
Co	0.05-0.14	0.03-0.22	0.07-0.66	0.01-0.16
Cr	0.01-0.06	0.01-0.04		
Cu	0.010-0.025	0.005-0.020		
F	0.76-1.6	1.2	0.69-2.5	0.81
Fe	8.2-157	720-890	360-870	380-590
Mn	25-37	41-54	17-115	12-20
Mo	0.05-0.09	0.08-0.09		
Ni	0.04-0.12	0.03-0.43	0.06-0.92	0.03-0.15
Pb	0.20-0.76	0.16-0.64	0.48-1.88	0.08-1.24
St	1.53-2.4	1.65-2.6	0.89-1.81	0.61-0.86
V	0.02-0.03	0.03-0.04		
Zn	0.010-0.200	0.010-0.175		

Note: pH is reported in standard units; all other parameters are in mg/L except where noted.

(from NUTP 1985 field program)

TABLE I.3.B-16

PORE WATER CHEMISTRY, KEY LAKE

pH	9.3-11.1
NH_3	25-40
NO_3	<0.005
SO_4	906-1650
Cl	24-35
HCO_3	0
CO_3	14-72
Ca	582-627
Na	26-43
Mg	0.61-4
K	6-17
D. Ra226	9.5-55 Bq/L
U	0.0014-0.005
Pb210	0.13-0.7 Bq/L
Po210	--
Th230	0.08-1.6 Bq/L
Al	0.13-0.66
As	0.26-2.2
B	<0.05
Ba	0.036-0.042
Cd	<0.005
Co	<0.005
Cr	<0.005
Cu	0.008-0.023
Fe	0.013-0.026
Mn	<0.005-0.033
Mo	0.43-1.2
Ni	0.016-0.087
Pb	<0.02-0.04
Si	1.8-4.1
V	0.15-0.16
W	0.23-0.25
Zn	0.02-0.032
Zr	<0.005

Note: pH is reported in standard units; all other parameters are in mg/L except where noted.

(from Knight and Piesold Ltd., 1985)

TABLE I.3.B-17

PORE WATER CHEMISTRY, RABBIT LAKE

pH	5.0-8.5
Cond	3700-4950
$O\text{-}PO_4$	0.03
TKN	358
NH_3	321
NO_3	5
SO_4	6350
Cl	210
HCO_3	35
CO_3	0
Ca	468
Na	154
Mg	956
K	31
T. Ra226	0.8-18.4 Bq/L
U	0.3-0.5
Po210	1.5-4.3 Bq/L
Th230	1.6-5.5 Bq/L
As	0.001
B	0.8
Ba	0.1
Cd	0.007
Co	0.15
Cr	0.02
Cu	0.06
F	1.1
Fe	0.25
Hg	<0.0001
Mn	0.4
Ni	0.4
Pb	0.1
V	<0.01
Zn	0.06

Note: pH is reported in standard units; all other parameters are in mg/L except where noted.

(from Melis Consulting Engineers Ltd., 1985)

I.4.0 DEPOSIT DESCRIPTIONS

I.4.1.A DEPOSIT DESCRIPTION, ONTARIO

As previously discussed there are ten tailings impoundments in the Elliot Lake district. See Figure I.1.A-1 for locations. In the following sections, the depositional history and layout of each area is described. In general the tailings management areas are situated in relatively impervious rock-rimmed depressions. Treated water is discharged into the Serpent River drainage basin.

i) Denison Mines Limited

Denison is responsible for the management of three tailings disposal sites, namely Denison Mine (Long Lake), Stanrock Mine and Williams Lake.

Tailings from the Denison Mine were first deposited, in 1957, immediately south of the plant into Smith Lake. Once this area reached its capacity, tailings were diverted to the west into Williams Lake until 1959. Since 1960, all of Denison's tailings have been deposited in the Denison Mine Tailings Area (formerly Long Lake).

The Stanrock tailings area was purchased by Denison in 1973. The impoundment at this time had already reached its full capacity.

Details on the history and characteristics of the Denison Mine, Williams Lake and Stanrock tailings management areas are listed in Table I.4.A-1,-2 and -3, respectively. Layout plans of the Denison and Williams Lake site are shown on Figure I.4.A-1. The layout plan of the Stanrock site is given on Figure I.4.A-2.

ii) Rio Algom Limited

As previously discussed Rio Algom Limited presently manages 6 tailings disposal sites in the vicinity of Elliot Lake. A summary table outlining the history and deposit description for each site is given in Table I.4.A-4, -5, -6, -7, -8 and -9 for the Quirke Mine, Stanleigh Mine, Panel Mine, Spanish American, Lacnor and Nordic Mine management areas, respectively. Layout plans for these areas are shown on Figure I.4.A-3, -4, -5, -1, -6 and -6, respectively.

I.4.1.B DEPOSIT DESCRIPTIONS, SASKATCHEWAN

The characteristics of the 6 major active or unreclaimed mill tailings deposits are given briefly in Tables I.4.B-1 to I.4.B-6 inclusive. General layouts of each of the deposits are illustrated in Figures I.4.B-1 to I.4.B-5 inclusive.

TABLE I.4.A-1

DENISON MINE TAILINGS MANAGEMENT AREA (formerly Long Lake)

LAYOUT OF DEPOSIT	- See Figure I.4.A-1
Area of Impoundment	- 182 ha
Depth of Tailings	- approximately 30 m in central portion
Area of Headpond	- approximately 1 ha
DEPOSITIONAL HISTORY	
Years of Operation	- 1960 to present
Rate of Deposition	- 10,000 tpd
Percent Solids	- 25 - 30%
Discharge Type & Location	- tailings have been discharged by open channel and now via a 508 mm pipe from the northeast portion of Long Lake
Total Tonnage Deposited	- approximately 45 million tonnes
Material Concentrations	- coarse at east end; fines at west end
SURFACE SLOPE AND DRAINAGE	
Regional Drainage	- in a valley nearly continuously rimmed by bedrock
Surface Gradients	- 1.3% at pipe, 0.6% at beach sands; 0.3% at slimes, 2% at water's edge; 0.5% overall
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- the basin is underlain by thick deposits of silty sand to sandy silt & sand & gravel ($k=10^{-4}$ m/s) overlying quartzites & conglomerates of the Gowganda Fm., diabase dykes & the Spanish American Fault bedrock $k=10^{-5}$ to 10^{-6} m/s, then 10^{-7} m/s below 7m
CLOSE OUT PREPARATION	- none; active
SURFACE WATER DISCHARGE	
Treatment Facilities	- barium chloride
Receiving Waters	- Serpent River
Surface Water Discharge	- a decant controls surface water; water from the treatment plant is discharged to Stollery Lake settling pond for clarification & precipitation of sludge
NATURAL REVEGETATION	- none; active fresh tailings
REFERENCES	- H.Q. Golder,1980c,1980a; Melis, 1985 Milligan et al,1977; Chakravatti,1986 LaRocque & Webber,1978; Laliberte,1986 J.F. MacLaren, 1977; Morrel, 1986

TABLE I.4.A-2

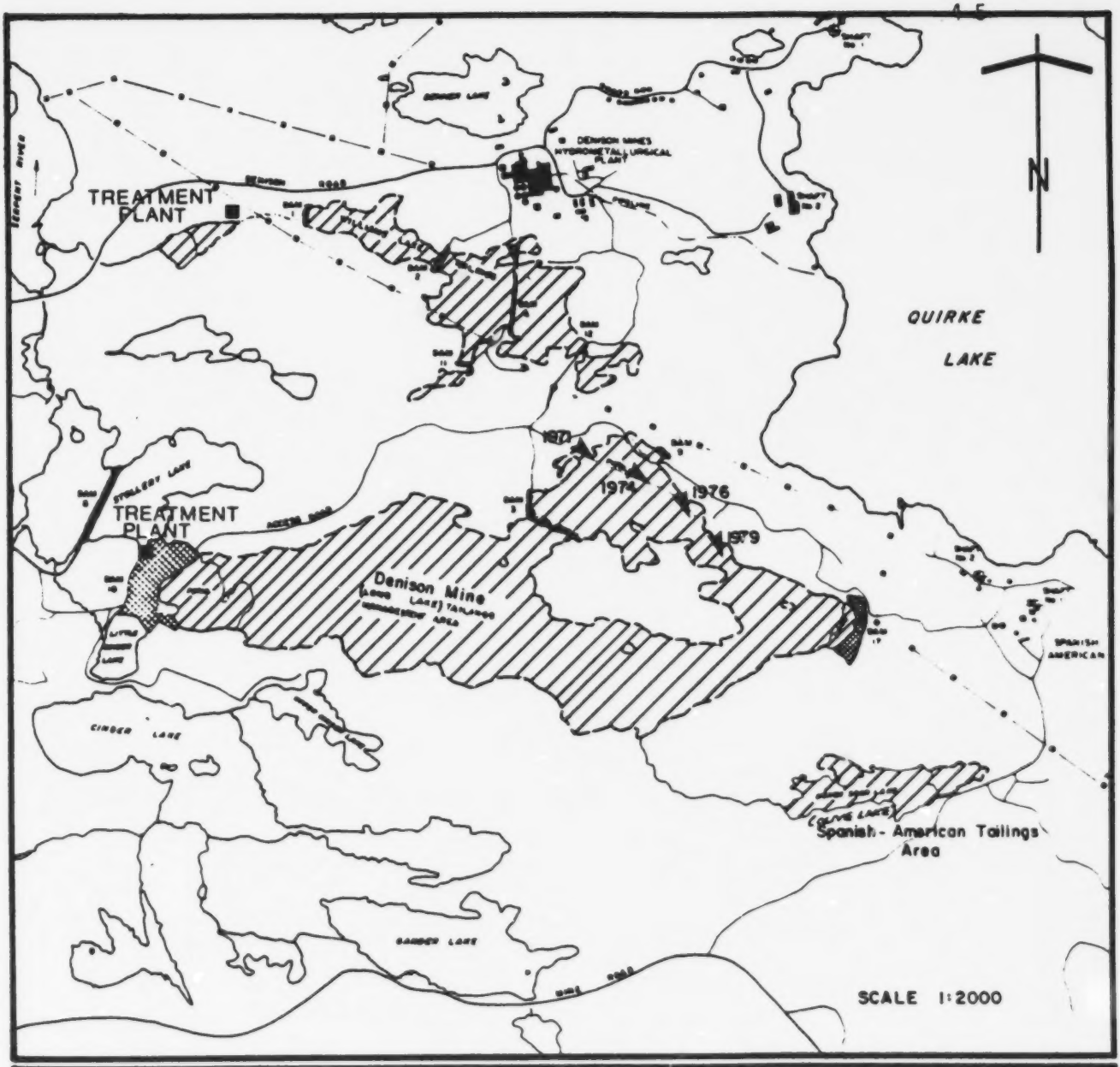
WILLIAMS LAKE TAILINGS MANAGEMENT AREA

LAYOUT OF DEPOSIT	- See Figure I.4.A-1
Area of Impoundment	- 7.3 ha
Depth of Tailings	- 12.2 m in the central portion
Area of Headpond	- approximately 1/2 to 3/4 of the area, the water table is at or near surface
DEPOSITIONAL HISTORY	
Years of Operation	- 1957 to 1959 by Denison
Rate of Deposition	- not available
Percent Solids	- 30 - 40%
Discharge Type & Location	- tailings were first discharged behind the plant in the form of a slurry into Smith Lk. then east to Williams Lake
Total Tonnage Deposited	- 0.9 million tonnes
Material Concentrations	- sands at east end, fines to the west
SURFACE SLOPE AND DRAINAGE	
Regional Drainage	- surrounding topography consist of rolling slopes (15%), drainage basin area = 21 ha
Surface Gradients	- 0.5%
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- the basin is underlain by thin deposits of till and discontinuous layers of silt & peat overlying relatively low permeability metamorphosed conglomerates, siltstones & arkoses of the Gowganda Fm.
CLOSE OUT PREPARATION	- studies are on-going to deposit a capping of thickened tailings to promote runoff
SURFACE WATER DISCHARGE	
Treatment Facilities	- lime & barium chloride
Receiving Waters	- Serpent River
Surface Water Discharge	- a spillway with stoplogs controls any overflow, seepage is diverted to the treatment plant & then via a lined trench to the settling pond
NATURAL REVEGETATION	- cattails, mosses and grasses
REFERENCES	- H.Q. Golder,1978g,1980c, Golder, 1981g; J.F. MacLaren, 1979b; Feenstra et al,1981; Reades et al,1981; LaRocque & Webber,1978; Laliberte,1986; Chakravatti, 1986

TABLE I.4.A-3

STANROCK TAILINGS MANAGEMENT AREA

LAYOUT OF DEPOSIT	- See Figure I.4.A-2
Area of Impoundment	- 61 ha
Depth of Tailings	- 20.9 m in the east central portion
Area of Headpond	- very small to nil since a spillway was excavated in 1979
DEPOSITIONAL HISTORY	
Years of Operation	- 1957-60 by Can-Met, 1958-64 by Stanrock
Rate of Deposition	- not available
Percent Solids	- 30 - 40%
Discharge Type & Location	- tailings have been discharged from all around the basin, Can-Met started from the north, Stanrock from the west
Total Tonnage Deposited	- approximately 7.5 millions tonnes
Material Concentrations	- coarse at north & west end; fines at east end
SURFACE SLOPE AND DRAINAGE	
Regional Drainage	- enclosed by two bedrock ridges drainage area is 78 ha
Surface Gradients	- 0.5%
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- the basin is underlain by thin deposits of sand & gravel and discontinuous layers of fine sand & silt & peat overlying relatively low permeability metamorphosed conglomerates greywackes & quartzites of the Gowganda Fm.
CLOSE OUT PREPARATION	- some natural revegetation; see below
SURFACE WATER DISCHARGE	
Treatment Facilities	- lime/sodium hydroxide & barium chloride
Receiving Waters	- Serpent River via Moose Lake
Surface Water Discharge	- a rock lined spillway controls surface water, water is diverted to the treatment plant & then to Moose Lake which is the settling pond
NATURAL REVEGETATION	- after quick lime was used poplars have grown, nothing grew prior to this due to wind erosion and acidity; root mat is about 250 mm
REFERENCES	- H.Q. Golder,1980c, Golder, 1981h; OWRC, 1969 Feenstra et al,1981; Chakravatti,1986 LaRocque & Webber,1978; Laliberte,1986



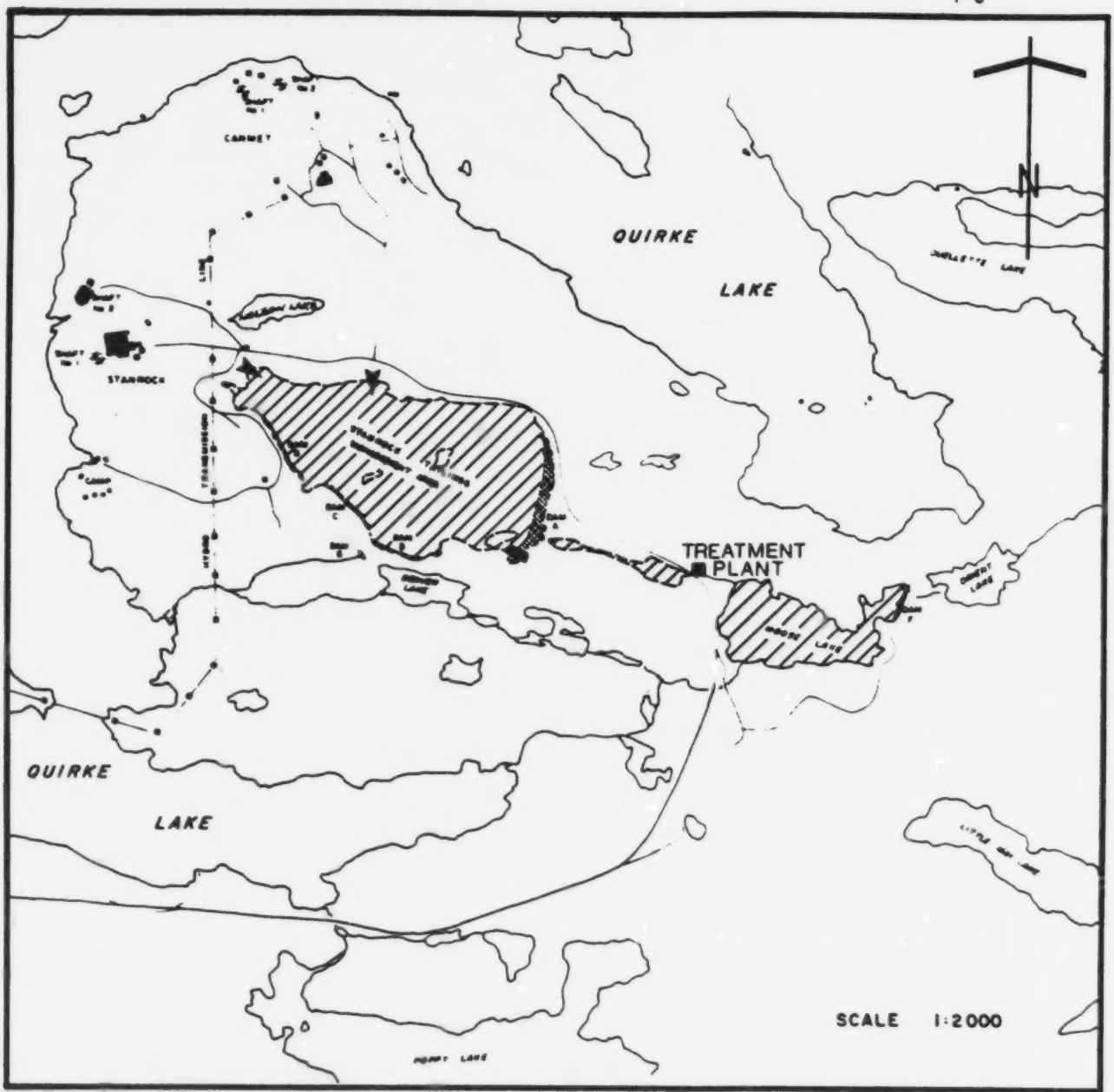
SITE PLAN

DENISON MINE, WILLIAMS LAKE AND SPANISH AMERICAN TAILINGS MANAGEMENT AREAS

Legend

◀ 1979 Discharge Location & Date

FIGURE I.4.A-1



SITE PLAN

STANROCK TAILINGS MANAGEMENT AREA

Legend

- Discharge Locations
- Spillway

FIGURE I.4.A-2

TABLE I.4.A-4

QUIRKE MINE TAILINGS MANAGEMENT AREA (Bud (Manfred) Lake)

LAYOUT OF DEPOSIT	- See Figure I.4.A-3
Area of Impoundment	- 162 ha
Depth of Tailings	- 18 m
Area of Headpond	- 30 to 68 ha
DEPOSITIONAL HISTORY	
Years of Operation	- 1956 to 1961, 1968 to present
Rate of Deposition	- 1.69 million tonnes/year
Percent Solids	- 25 to 30%
Discharge Type & Location	- tailings were first discharged from east to west then from west to east via a 406 mm pipe into cells
Total Tonnage Deposited	- 35.4 millions tonnes
Material Concentrations	- not available
SURFACE SLOPE AND DRAINAGE	
Regional Drainage	- surrounding topography consists of rolling slopes (max. relief 90m); drainage basin area is 468 ha
Surface Gradients	- 0.5%
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- the basin is underlain by generally thin deposits of granular soils and till ($k=10^{-5}$ to $^{-7}$ m/s) overlying Huronian metamorphosed conglomerates, siltstones, quartzites ($k=10^{-5}$ to 10^{-8}m/s; >6m depth, 10^{-8}m/s)
CLOSE OUT PREPARATION	- nothing at present
SURFACE WATER DISCHARGE	
Treatment Facilities	- lime & barium chloride
Receiving Waters	- Serpent River to Quirke Lake
Surface Water Discharge	- a spillway controls overflow, treated water is clarified in a series of three settling ponds
NATURAL REVEGETATION	- bullrushes
REFERENCES	- Golder,1981; J.F. MacLaren, 1977b; Melis, 1985; MacLaren & Golder 1980; Vivyurka, 1986 Maltby, 1986; J.F.MacLaren & Golder,1980

TABLE I.4.A-5

STANLEIGH MINE TAILINGS MANAGEMENT AREA (Stanleigh & Milliken Mines)

LAYOUT OF DEPOSIT	- See Figure I.4.A-4
Area of Impoundment	- 400 ha
Depth of Tailings	- 12 to 18 m
Area of Headpond	- 310 ha
DEPOSITIONAL HISTORY	
Years of Operation	- 1958-60 (Stanleigh), 1958-64 (Milliken),1983 to present
Rate of Deposition	- 1.2 million tonnes/year
Percent Solids	- 25 to 30%
Discharge Type & Location	- tailings were discharged into the south west corner of the lake, presently they are deposited into northwest corner
Total Tonnage Deposited	- 10.34 million tonnes
Material Concentrations	- not available
SURFACE SLOPE AND DRAINAGE	
Regional Drainage	- situated in a glaciated valley between bedrock uplands, drainage area 1110 ha
Surface Gradients	- 3% first 120m, 2% next 240m, 1% next 360m 0.5% thereafter, 0.5% overall
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- the basin is underlain by generally thin deposits of peat, granular soils and till (depth <3m) overlying Huronian metasedimentary rocks ($k=10^{-6}$ to 10^{-10} m/s)
CLOSE OUT PREPARATION	- revegetated in small area
SURFACE WATER DISCHARGE	
Treatment Facilities	- lime & barium chloride
Receiving Waters	- MacCabe Lake to Serpent River system
Surface Water Discharge	- a decant and spillway control overflow, clarification is accomplished by sand filtration in dual-media sand filters, precipitate is pumped back to the pond
NATURAL REVEGETATION	- some revegetation, also bullrushes
REFERENCES	- H.Q. Golder and Associates Ltd.,1978a,1980d; J.F. MacLaren, 1977b; MacLaren & Golder, 1979b,81a; Vivyurka, 1986; Boyd et al, 1982;

TABLE I.4.A-6

PANEL MINE TAILINGS MANAGEMENT AREA (formerly Strike Lake)

LAYOUT OF DEPOSIT	- See Figure I.4.A-5
Area of Impoundment	- 70 ha
Depth of Tailings	- 21 m
Area of Headpond	- 40 ha of area covered with water
DEPOSITIONAL HISTORY	
Years of Operation	- 1958-60 (Northspan Uranium) , 1960-61 (Rio); 1978 to present
Rate of Deposition	- 0.99 million tonnes/year
Percent Solids	- 25 to 30%
Discharge Type & Location	- tailings were discharged from the south-west
Total Tonnage Deposited	- 9.37 million tonnes
Material Concentrations	- not available
SURFACE SLOPE AND DRAINAGE	
Regional Drainage	- situated in a glaciated valley between bedrock uplands,
Surface Gradients	- 0.5%
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- the basin is expected to be underlain by deposits of peat, granular soils and till overlying Huronian metasedimentary rocks
CLOSE OUT PREPARATION	- revegetated in small area
SURFACE WATER DISCHARGE	
Treatment Facilities	- lime & barium chloride
Receiving Waters	- Quirke Lake
Surface Water Discharge	- tailings decant water is collected, treated and clarified in lined settling ponds
NATURAL REVEGETATION	- some revegetation, also bullrushes
REFERENCES	- J.F. MacLaren, 1977b; Vivyurka, 1986; Pullen & Davis, 1981; Melis, 1985;

TABLE I.4.A-7

SPANISH AMERICAN TAILINGS MANAGEMENT AREA (Olive Lake)

LAYOUT OF DEPOSIT	- See Figure I.4.A-1
Area of Impoundment	- 10 ha
Depth of Tailings	- 6 m
Area of Headpond	- 7.5 ha of area covered with water
DEPOSITIONAL HISTORY	
Years of Operation	- 1958 to 1959
Rate of Deposition	- not available
Percent Solids	- not available
Discharge Type & Location	- tailings were discharged from the east
Total Tonnage Deposited	- 0.45 million tonnes
Material Concentrations	- not available
SURFACE SLOPE AND DRAINAGE	
Regional Drainage	- situated in a glaciated valley between bedrock uplands,
Surface Gradients	- 0.5%
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- the basin is expected to be underlain by deposits of peat, granular soils and till overlying Huronian metasedimentary rocks
CLOSE OUT PREPARATION	- revegetated in small area
SURFACE WATER DISCHARGE	
Treatment Facilities	- none
Receiving Waters	- Denison Mine Tailings area
Surface Water Discharge	- no control measures
NATURAL REVEGETATION	- some revegetation, also bullrushes
REFERENCES	- J.F. MacLaren, 1977b; Vivyurka, 1986;

TABLE I.4.A-8

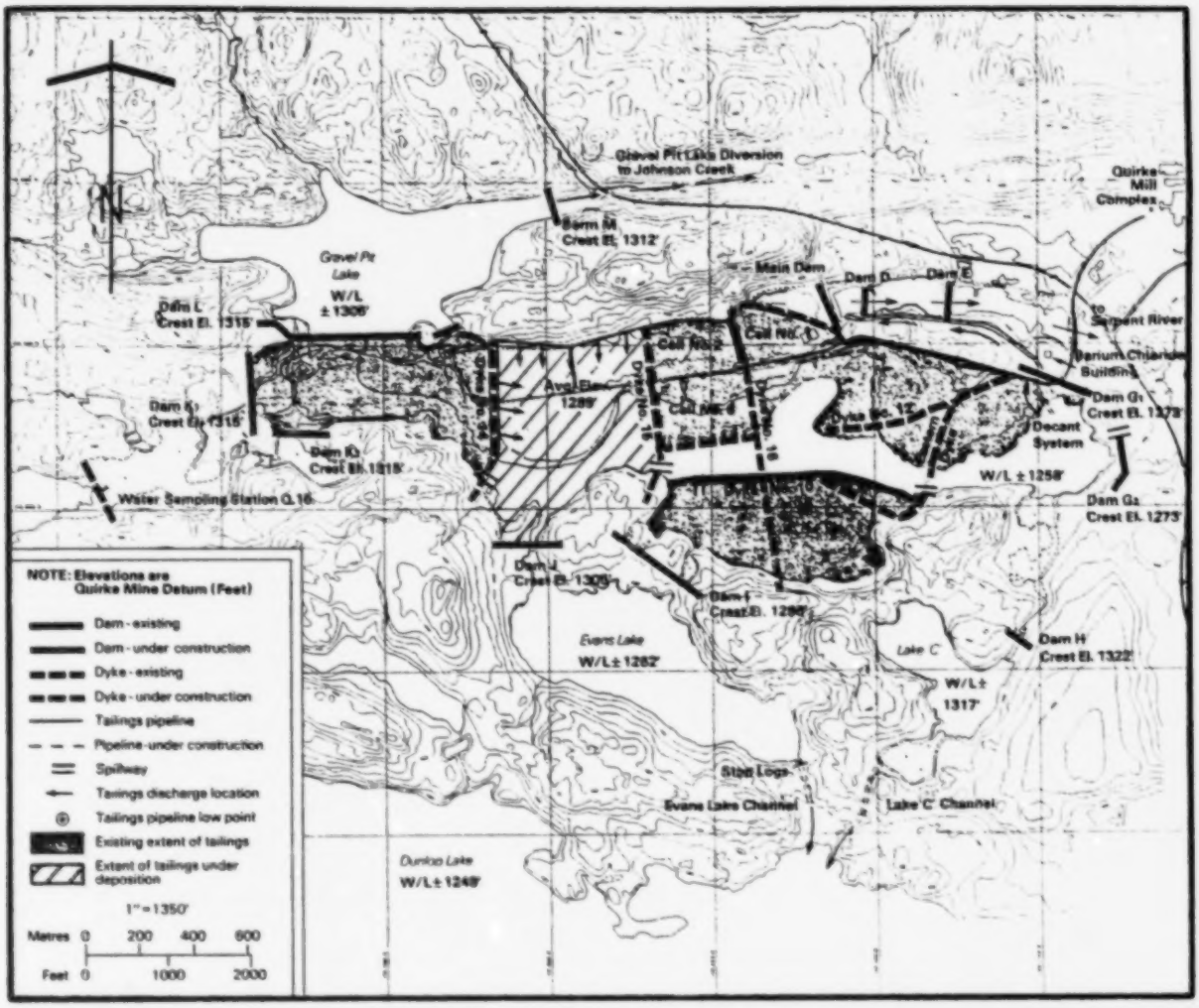
LACNOR TAILINGS MANAGEMENT AREA

LAYOUT OF DEPOSIT	- See Figure I.4.A-6
Area of Impoundment	- 24 ha
Depth of Tailings	- 9 m
Area of Headpond	- water table close to surface
DEPOSITIONAL HISTORY	
Years of Operation	- 1957 to 1960 (Lacnor & Buckles Mine)
Rate of Deposition	- not available
Percent Solids	- not available
Discharge Type & Location	- tailings were discharged from the west
Total Tonnage Deposited	- 2.7 millions tonnes
Material Concentrations	- fines in east, coarse to west
SURFACE SLOPE AND DRAINAGE	
Regional Drainage	- situated in a glaciated valley between bedrock uplands
Surface Gradients	- 0.5%
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- the basin was a former lake bog & stream deposits of peat, granular soils and till overlying Huronian rocks are anticipated
CLOSE OUT PREPARATION	- revegetated
SURFACE WATER DISCHARGE	
Treatment Facilities	- treated at Nordic
Receiving Waters	- Nordic tailings area to Nordic Lake
Surface Water Discharge	- a decant controls any overflow, seepage and runoff is channelled westward into North Nordic Lk. where it is treated and precipitate is settled out
NATURAL REVEGETATION	- revegetated
REFERENCES	- H.Q. Golder,1978a; J.F. MacLaren, 1979a, 1977b; Vivyurka, 1986; Cherry et al, 1980.

TABLE I.4.A-9

NORDIC MINE TAILINGS MANAGEMENT AREA

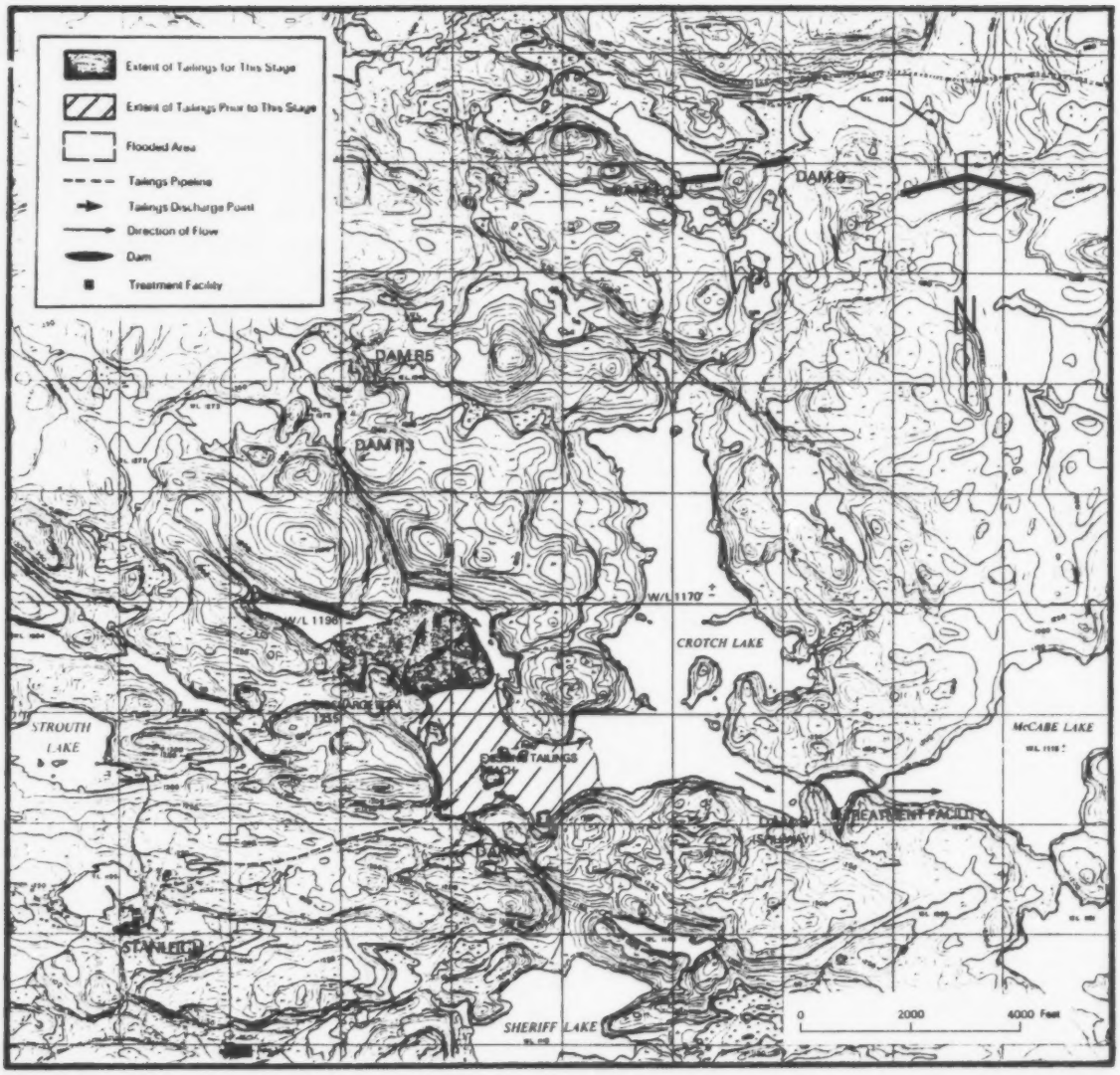
LAYOUT OF DEPOSIT	- See Figure I.4.A-6
Area of Impoundment	- 85 ha
Depth of Tailings	- main dyke 12 m, west arm 7 m
Area of Headpond	- none presently, depth to water 1-10m
DEPOSITIONAL HISTORY	
Years of Operation	- 1957 to 1968
Rate of Deposition	- not available
Percent Solids	- not available
Discharge Type & Location	- tailings were discharged from the top of the embankments, generally from the south west
Total Tonnage Deposited	- 12 million tonnes
Material Concentrations	- fines in northeast, coarse to southwest
SURFACE SLOPE AND DRAINAGE	
Regional Drainage	- situated in a glaciated valley between bedrock uplands
Surface Gradients	- 0.5%
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- the basin is underlain by generally thin deposits of peat, granular soils and till ($k=10^{-4}$ to $^{-5}$ m/s) overlying Huronian metasedimentary rocks
CLOSE OUT PREPARATION	- revegetated
SURFACE WATER DISCHARGE	
Treatment Facilities	- lime & barium chloride
Receiving Waters	- Nordic Lake
Surface Water Discharge	- a decant controls any overflow; seepage and runoff is channelled westward into North Nordic Lk. where it is treated and precipitate is settled out
NATURAL REVEGETATION	- revegetated, also bullrushes and willows
REFERENCES	- H.Q. Golder,1978a; J.F. MacLaren, 1977b; 1979a; Vivyurka, 1986; Blowes, 1983; Dave et al, 1981; Dubrovsky et al, 1985; Morin et al, 1982;



SITE PLAN

QUIRKE TAILINGS MANAGEMENT AREA

FIGURE I4.A-3

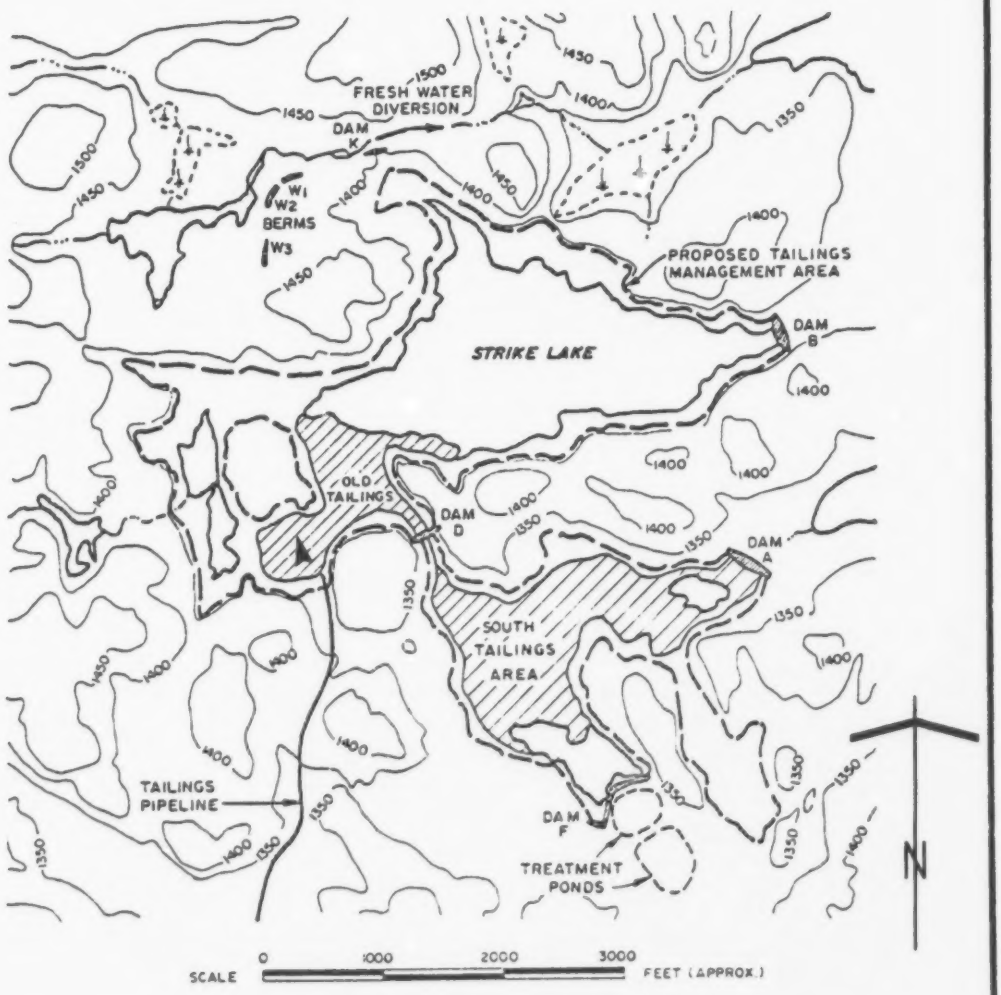


SITE PLAN

STANLEIGH MINE

TAILINGS MANAGEMENT AREA

FIGURE I.4.A-4



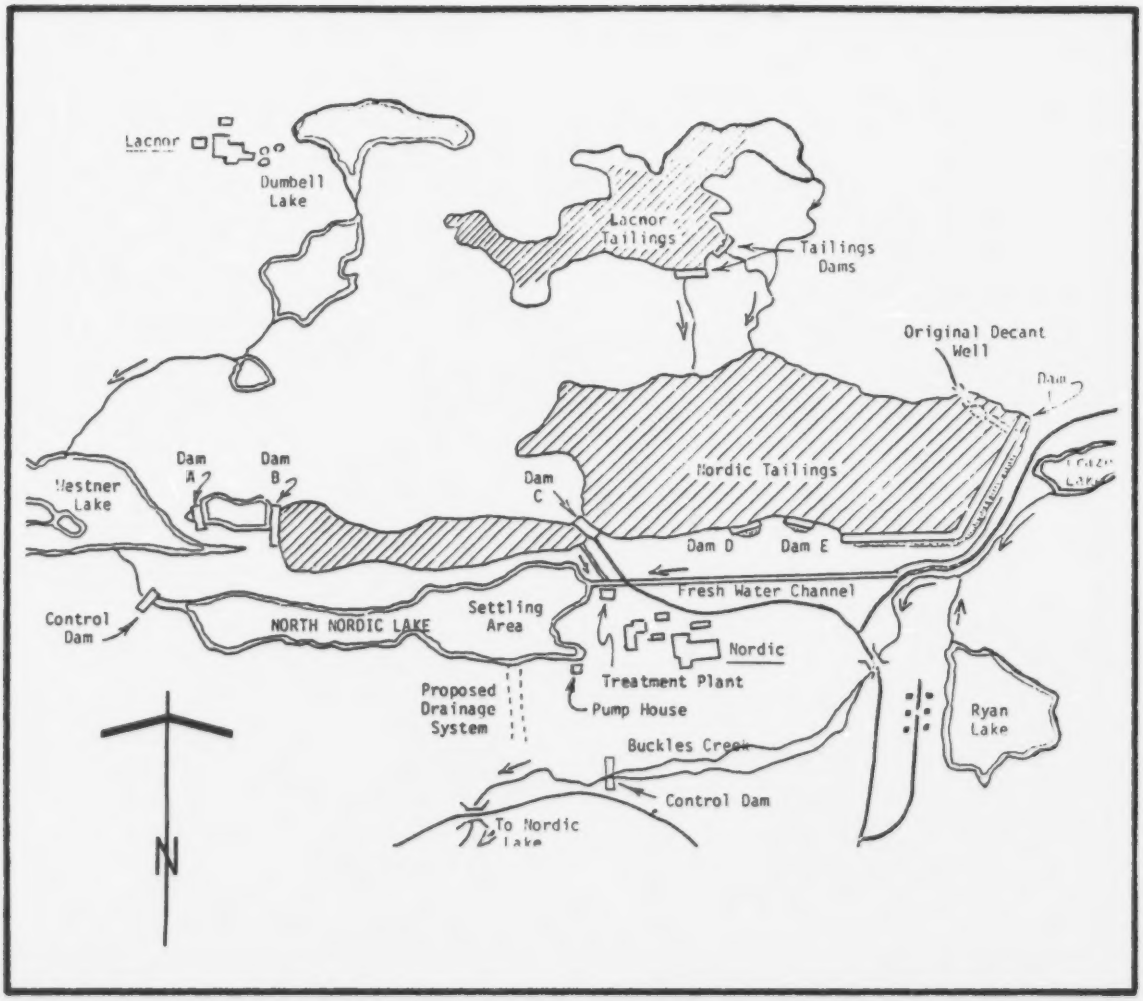
SITE PLAN

PANEL TAILINGS MANAGEMENT AREA

Legend

▲ Discharge Location

FIGURE I.4.A-5



SITE PLAN

NORDIC AND LACNOR TAILINGS MANAGEMENT AREAS

FIGURE I.4.A-6

TABLE I.4.B-1

CLUFF LAKE MINE TAILINGS MANAGEMENT AREA

LAYOUT OF DEPOSIT	- see Figure I.4.B-1
Area of Impoundment	- 94 ha with potential expansion to 172 ha
Area of Headpond	- unknown
DEPOSITIONAL HISTORY	
Years of Operation	- 1981 to present
Rate of Deposition	- 350,000 to 500,000 tonnes/year - estimate
Percent Solids	- estimated at 75 %
Discharge Type and Location	- mass discharge to pond
Total Tonnage Deposited	- estimated final up to 7,500,000 tonnes
Material Concentrations	- slimes at centre and away from dam is desired
SURFACE CONDITIONS	
Regional Drainage	- on rim of Snake Lake drainage basin; uniform cross slope to Snake Lake
Surface Gradients	- approximately 1 %
Natural Vegetation	- muskeg and dwarf wetland vegetation. black spruce.
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- the basin is underlain by thin sand and till overlying fractured quartzose sandstone of the Athabasca Formation; some permafrost encountered in surficial sediments
CLOSE OUT PREPARATION	- presently under study
SURFACE WATER DISCHARGE	
Treatment Facilities	- barium chloride and coagulant; sedimentation ponds and dual media (sand and anthracite) filtration
Receiving Waters	- Snake Lake; Douglas River
Surface Water Discharge	- from secondary treatment system to a tributary of Douglas River system
NATURAL REVEGETATION	- revegetation studies ongoing
REFERENCES	- W.A. Meneley Consultants Ltd., no date; Stearns-Roger Incorporated, 1976a

TABLE I.4.B-2

GUNNAR MINE TAILINGS MANAGEMENT AREA

LAYOUT OF DEPOSIT	- see Figure I.4.B-2
Area of Impoundment	- 74.8 ha
Area of Headpond	- n/a
DEPOSITIONAL HISTORY	
Years of Operation	- 1955 - 1963
Rate of Deposition	- unknown
Percent Solids	- unknown
Discharge Type and Location	- mass discharge to a natural lake, Mudford Lake, and through natural drainage courses to Langley Bay of Lake Athabasca
Total Tonnage Deposited	- 4.4×10^6 tonnes
Material Concentrations	- coarse near discharge and finer near edges but influenced by cycloned tailings dykes
SURFACE CONDITIONS	
Regional Drainage	- a natural lake basin connected by natural drainage courses to Lake Athabasca
Surface Gradients	- variable, from 7 % and greater
Natural Vegetation	- mixed softwood forest, peat
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- the topography is controlled by bedrock features; bedrock is overlain by glacial-lacustrine silt and peat
CLOSE OUT PREPARATION	- none
SURFACE WATER DISCHARGE	
Treatment Facilities	- none
Receiving Waters	- Langley Bay of Lake Athabasca
Surface Water Discharge	- uncontrolled discharge of water and tailings to Lake Athabasca
NATURAL REVEGETATION	- variable from 0 to 100 percent
REFERENCES	- Whiting et al, 1982; Swanson and Abouguendia, 1981

TABLE I.4.B-3

KEY LAKE MINE TAILINGS MANAGEMENT AREA

LAYOUT OF DEPOSIT	- see Figure I.4.B-3
Area of Impoundment	- 45 ha
Area of Headpond	- approximately 15 ha
DEPOSITIONAL HISTORY	
Years of Operation	- 1983 to present
Rate of Deposition	- 25,000 tonnes/y estimated
Percent Solids	- 24%
Discharge Type and Location	- in thin layers (less than 100 m) using subaerial technique in summer; mass discharge in layers of 1,000 mm or more in winter
Total Tonnage Deposited	- estimated 4,200,000 tonnes final
Material Concentrations	- no segregation in summer discharge; some segregation in winter discharge
SURFACE CONDITIONS	
Regional Drainage	- at the head end of a water shed; drainage to Gerald Lake, Wolf Lake and finally to the Wheeler River system
Surface Gradients	- steep till ridges with lower gradient valleys.
Natural Vegetation	- dwarf pioneer jack pine growth in old burned area
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- drumlinized silty till on drumlins; clean plain; Athabasca Formation sandstone at depth; piezometric levels approximately controlled by bedrock elevation
CLOSE OUT PREPARATION	- incorporated in the design; surface to be contoured and shaped and covered
SURFACE WATER DISCHARGE	
Treatment Facilities	- barium chloride, lime and filtration
Receiving Waters	- Gerald Lake and eventually Wheeler River system
Surface Water Discharge	- carefully controlled; batch discharge from monitoring ponds
NATURAL REVEGETATION	- none, revegetation studies ongoing
REFERENCES	- Knight and Piesold Ltd., 1985a

TABLE I.4.B-4

LORADO MINE TAILINGS MANAGEMENT AREA

LAYOUT OF DEPOSIT	- see Figure I.4.B-4
Area of Impoundment	- 14.2 ha
Area of Headpond	- n/a
DEPOSITIONAL HISTORY	
Years of Operation	- 1957 - 1961
Rate of Deposition	- not known
Percent Solids	- not known
Discharge Type and Location	- mass discharge to Nero Lake
Total Tonnage Deposited	- approximately 545,000 tonnes
Material Concentrations	- coarse near discharge; fines in Nero Lake; the tailings become finer with depth with medium grained sand on top and silt sizes at base of deposit
SURFACE CONDITIONS	
Regional Drainage	- directly to Nero Lake and eventually to Lake Athabasca
Surface Gradients	- n/a
Natural Vegetation	- mixed softwood
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- up to 10 m of calcareous and noncalcareous peat overlying fractured bedrock
CLOSE OUT PREPARATION	- none
SURFACE WATER DISCHARGE	
Treatment Facilities	- none
Receiving Waters	- Nero Lake; Lake Athabasca
Surface Water Discharge	- no control
NATURAL REVEGETATION	- extremely sparse, restricted to edges of tailings
REFERENCES	- Whiting et al, 1982.

TABLE I.4.B-5

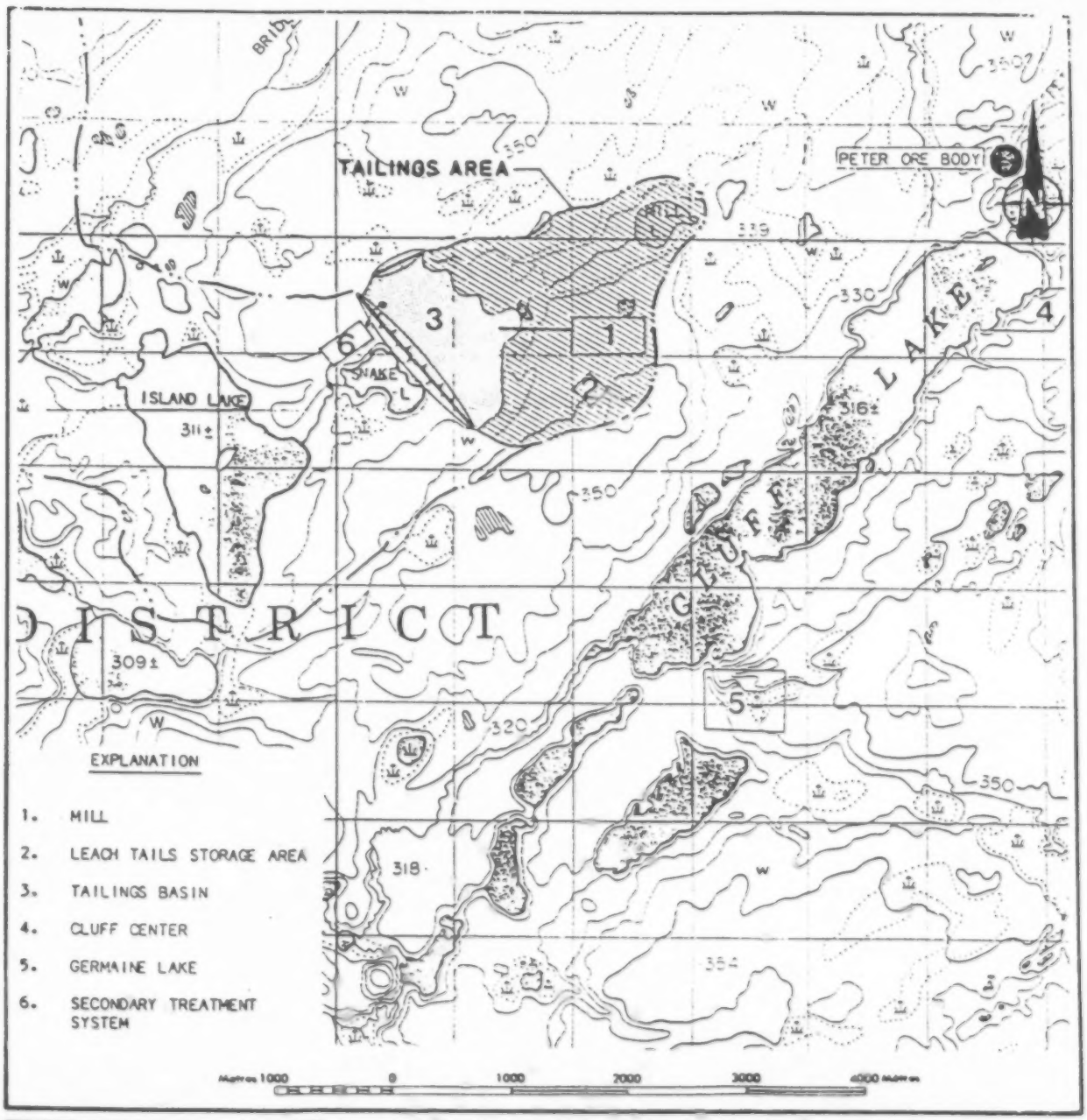
RABBIT LAKE MINE TAILINGS MANAGEMENT AREA

LAYOUT OF DEPOSIT	- see Figure I.4.B-5
Area of Impoundment	- 53.8 ha in 1982
Area of Headpond	- estimated from 6 to 17 ha
DEPOSITIONAL HISTORY	
Years of Operation	- 1972 - 1985
Rate of Deposition	- estimated at 3500 tonnes/day in 1984
Percent Solids	- estimated at 40 %
Discharge Type and Location	- mass discharge to engineered dam
Total Tonnage Deposited	- estimated 5,870,000 tonnes
Material Concentrations	- more fines (slimes) in central portion, maximum thickness 20 to 23 m
SURFACE CONDITIONS	
Regional Drainage	- in a bedrock valley confined by dams at upstream and downstream ends
Surface Gradients	- laterally steep into reservoir; flatter along valley
Natural Vegetation	- coniferous forest, primarily black spruce
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- the basin is underlain by thin peat and glacial till overlying fractured bedrock with complex regional structure; artesian flows noted during site investigations; springs evident along rock ridges
CLOSE OUT PREPARATION	- presently being studied.
SURFACE WATER DISCHARGE	
Treatment Facilities	- barium chloride, settling ponds, filtration and pH adjustment
Receiving Waters	- Wollaston Lake
Surface Water Discharge	- continuous after passing through secondary treatment system
NATURAL REVEGETATION	- not known
REFERENCES	- Eldor Mines Limited, 1985; MacLaren Engineers Inc., 1984

TABLE I.4.B-6

COLLINS BAY B-ZONE TAILINGS MANAGEMENT AREA (RABBIT LAKE PIT)

LAYOUT OF DEPOSIT	- see Figure I.4.B-5
Area of Impoundment	- n/a
Area of Headpond	- n/a
DEPOSITIONAL HISTORY	
Years of Operation	- beginning in 1985
Rate of Deposition	- not available
Percent Solids	- not available
Discharge Type and Location	- filtered tailings hauled to pit by wheeled transport
Total Tonnage Deposited	- not available
Material Concentrations	- n/a
SURFACE CONDITIONS	
Regional Drainage	- waste system is in Rabbit Lake Pit, an open pit developed in the bottom of the dewatered Rabbit Lake
Surface Gradients	- relatively level across site
Natural Vegetation	- coniferous forest
SUBSURFACE CONDITIONS	
Geology and Hydrogeology	- surficial sediments around the pit are thin fluvial lacustrine sediments and till overlying highly fractured Athabasca Formation sandstone and basement rocks; the Pow Bay fault transects the pit
CLOSE OUT PREPARATION	- dewatering and consolidation of tailings; covering with waste rock and flooding
SURFACE WATER DISCHARGE	
Treatment Facilities	- barium chloride, settling ponds, filtration and pH adjustment
Receiving Waters	- Wollaston Lake
Surface Water Discharge	- continuous after secondary treatment
NATURAL REVEGETATION	- not known
REFERENCES	- Gulf Minerals Canada Ltd., 1981a, b, c; MacLaren Engineers Inc., 1984

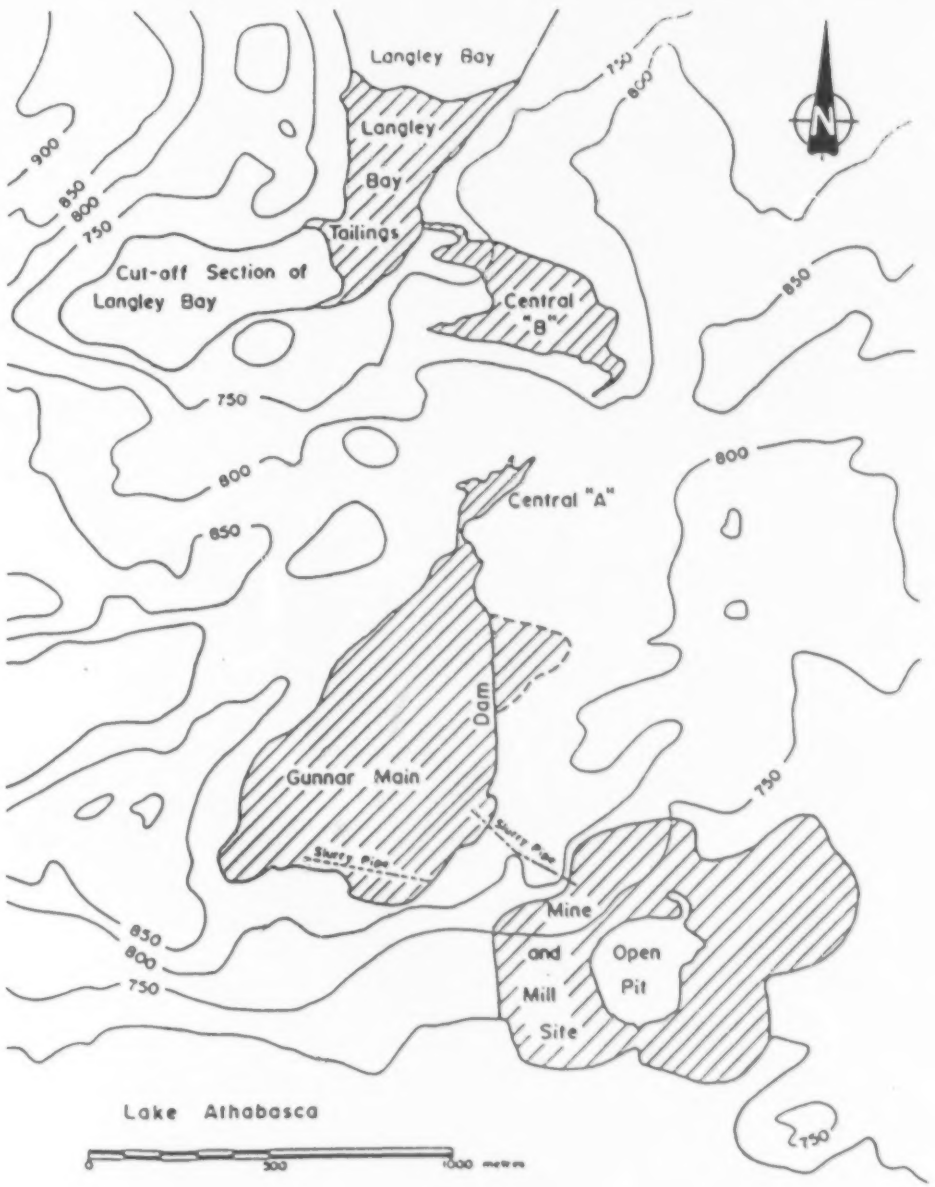


SITE PLAN

CLUFF LAKE TAILINGS MANAGEMENT AREA

(FROM CLUFF MINING, 1982)

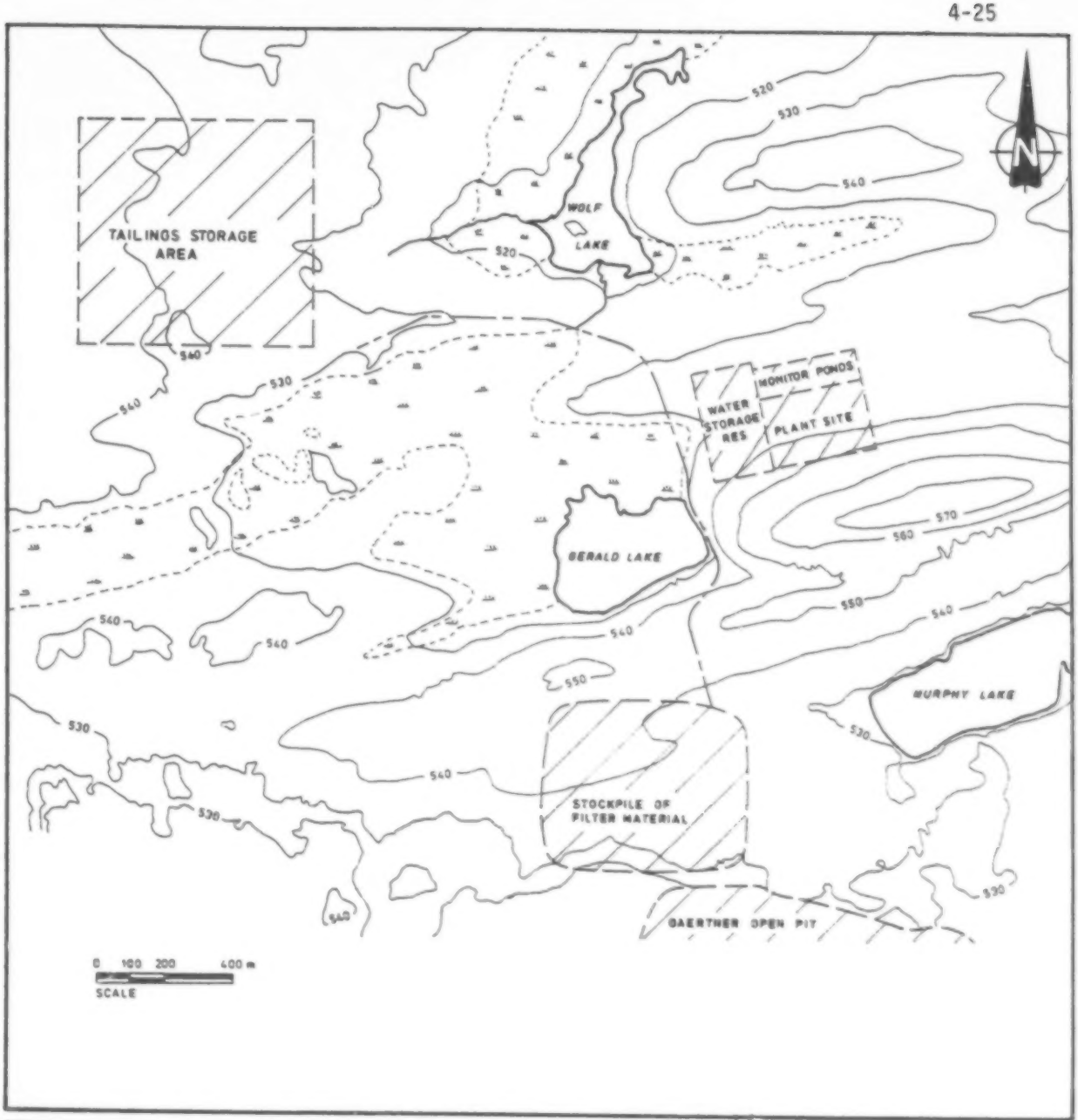
FIGURE I. 4. B-1



SITE PLAN

GUNNAR TAILINGS MANAGEMENT AREA
(FROM SWANSON & ABOUGUENDIA, 1981)

FIGURE I.4. B-2



SITE PLAN

KEY LAKE TAILINGS MANAGEMENT AREA

(FROM KEY LAKE MINING CORPORATION 1981a)

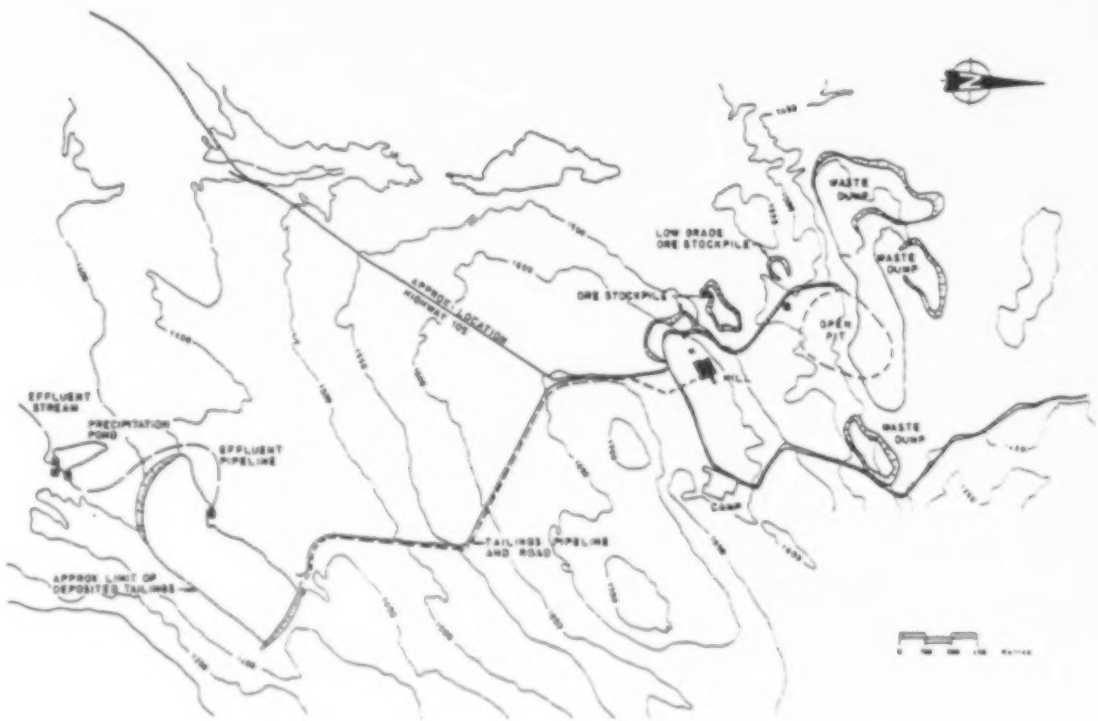
FIGURE I.4.B-3

SITE PLAN

LORADO TAILINGS MANAGEMENT AREA

(FROM SWANSON & ABOUGUENDIA, 1981)

FIGURE I. 4. B - 4



SITE PLAN

RABBIT LAKE TAILINGS MANAGEMENT AREA

(FROM MacLAREN ENGINEERS INC, 1984)

FIGURE I. 4. B - 5

I.5.0 SURFACE AND HYDROLOGY CHARACTERISTICS

I.5.1.A POTENTIAL FOR REVEGETATION, ONTARIO

Certain locations on the inactive tailings areas have been naturally colonized by indigenous species (Kalin, 1983). However, the overall physical and chemical environments of the inactive areas are such that natural colonization would not be expected to occur for very many decades. Low pH, variable salt concentrations, a virtually complete absence of plant macro-nutrients (Mine Waste Reclamation 1981) in conjunction with water and wind erodible surfaces and high surface temperatures present an environment unsuitable for natural plant succession processes typical of other disturbed non-tailings areas in the region. The establishment of a continuous and acceptable plant cover will be dependent on either assessing the tailings in situ or covering them with other materials more conducive to plant growth.

Revegetation studies were begun by Rio Algom on inactive tailings areas in 1970. Since that time there have been numerous reports prepared and papers published describing various aspects of revegetation studies in the Elliot Lake region (e.g., Dunn et al, 1977); Watkin and Winch, 1973; Murray, 1977; Murray and Moffet, 1977; Murray, Webber and LaRocque, 1978; Mine Waste Reclamation 1980a, 1980b, 1080c, 1980d, 1981; Kalin, 1983). Similar revegetation studies were begun elsewhere in Canada at the same time also on tailings areas characterized by the presence of iron sulphides (e.g. Brooks, 1981; Gardiner, 1977.) During the period 1970 to 1978 approximately, the majority of the studies were concerned with finding solutions to overcome the acidic nature of the various tailings disposal areas and which would permit the implementation of large scale field reclamation programs. Because of that, the major proportion of vegetation established during the 1970-1978 period was in the form of numerous experimental areas rather than large area blocks.

A review of the success of revegetation programs at some of the inactive impoundments indicates the vegetation will hold its own once it has been established. The depth of root mats at these sites are in the order of 250 to 300 mm (Chakravatti, 1986 and Vivyurka, 1986).

I.5.1.B POTENTIAL FOR REVEGETATION, SASKATCHEWAN

The limiting factors in revegetating tailings areas are climate, the lack of nutrients in the tailings, salinity and in the case of the Lorado tailings, acidity. In addition, local toxicity due to metals or trace elements may preclude revegetation.

Swanson and Abouguendia (1981) briefly reported on the results of the one attempt to induce revegetation on the Beaverlodge tailings where three legumes and nine grasses were tested under varying treatments including watering, fertilization and addition of peat. The experiments were relatively successful and native species had started to invade the test plots within three to four years after initial seeding. Additional experiments have been conducted by Amok Ltd. (1985), KLMC (1984) and Eldorado Resources Limited. (1984). The Amok experiments are of particular

interest since these included works on revegetating waste rock which may be the candidate material for cover on decommissioned tailings areas.

Substantial work has been directed toward natural revegetation of the abandoned tailings piles at Gunnar and Lorado. Redmann and Frankling (1982), Kalin (1981), Whiting et al (1982) and Swanson and Abouguendia (1981) have all reported on their observations at the Gunnar and the Lorado sites. Their conclusions are similar.

Redmann and Frankling (1982) reported that Gunnar tailings had a pH of 4.8 to 6.9 and conductivity ranging from 1.6 to 15.0 mmhos/cm (non-saline to strongly saline). The tailings had low levels of nitrogen, phosphorus and potassium while calcium and magnesium levels were relatively high. Gradation ranged from silt to medium sand. Kalin (1981) reported that natural vegetation communities had been established on approximately two thirds of the total tailings area. The remainder was wind blown tailings which had covered tree trunks up to 1 m in depth in areas adjoining the perimeter of the unstable areas. The observed cover was of two types: native grasses invading compact dry tailings; and, dense wetland species dominated by sedges and brushes which surrounded the small ponds and completely stabilized the surface.

Redmann and Frankling (1982) reported that the conditions at the Nero Lake tailings were similar to those at Gunnar: the main differences being a low pH (2.5 - 3.9), potentially toxic levels of manganese, iron and lead, and higher sulphate levels. Kalin (1981) also reported high sulphur levels (5%) and observed that no suitable vegetation had invaded the tailings areas. Further, the opinion was expressed that there was little chance of successful stabilization with vegetation if the existing conditions prevailed.

Analyses of water soluble nutrients for the Gunnar and Lorado tailings are presented in Tables I.5.B-1 and -2.

Amok Ltd. (1985) report results of reclamation and revegetation of the D ore body at Cluff Lake, the area surrounding the secondary treatment pond, and the downstream slope of the tailings dam. The areas were hydroseeded with grasses and good coverage was reported. Additional evaluation of results is underway.

I.5.2.A WIND EROSION AND DISPERSION, ONTARIO

Wind erosion has generally taken place at each of the tailings impoundments where the sands are either not covered with water or capped. The most pronounced wind erosion has taken place at the Stanrock site. Work done by Dave et al (1985) indicates wind transported tailings have been found 1 km downwind of the site.

To combat against the wind's erosive nature, a number of techniques have been used successfully in the area. These include the application of lime, bark or straw mulch to the surface, a complete revegetation program and/or flooding of the tailings.

TABLE I.5.B-1

AVAILABLE NUTRIENTS, GUNNAR

TAILINGS AREA	SITE NUMBER	DEPTH (mm)	AVAILABLE NUTRIENTS (ug/g soil) NO_3-N	P	K	SO_4-S
GUNNAR MAIN	2A	0-100	1	1	15	750
	2B	250-350	1	1	15	700
	4A	0-100	1	1	20	700
	4B	250-350	1	1	15	700
GUNNAR CENTRAL	5A	0-100	1	1	25	1800
LANGLEY BAY	7A	0-100	1	1	30	1450

(from Redmann and Frankling, 1982)

TABLE I.5.B-2

AVAILABLE NUTRIENTS, LORADO

TAILINGS AREA	SITE NUMBER	DEPTH (mm)	AVAILABLE NUTRIENTS (ug/g soil) NO_3-N	P	K	SO_4-S
NERO LAKE	2A	0-60	1	3	5	2150
	2B	250-350	1	3	15	2300
	4A	30-100	1	5	5	1000
	4B	250-350	1	2	10	1000
	6A	0-100	1	6	15	60

(from Redmann and Frankling, 1982)

I.5.2.B WIND EROSION AND DISPERSION, SASKATCHEWAN

Significant wind erosion has been reported at the Gunnar and Lorado sites. The upper portion of the Gunnar site is particularly unstable and wind transported tailings up to 1 m in depth have been reported in natural vegetation around the tailings perimeter (Kalin, 1981). The Lorado tailings were reported by Swanson and Abouguendia (1981) as generally lacking natural vegetation and being subject to both wind and water erosion. The same authors reported that the only natural revegetation was some grasses (mainly reed grass) that were sparsely established where the tailings were thin, and some young birch trees which were invading the edges of the tailings.

Few other problems with wind erosion and dispersion of solids are reported. The surface of the neutralized tailings is quite stable after initial drying, probably through cementing with gypsum. This crusting provides an erosion-resistant surface during the summer unless repeatedly wetted and dried by precipitation. This cycle breaks down the crust, making it more susceptible to local erosion. A similar process is noted during spring breakup; the effects of freezing and thawing and leaching of the surface leaves an unstable, friable surface subject to wind erosion.

I.5.3.A RADON EMANATION, ONTARIO

Radon emanation from the tailings areas in Elliot Lake has been measured by both aerodynamic and accumulation methods. The average emanation rates measured by MacLaren, 1978b and DSMA Atcon, 1985 are presented in Table I.5.A-1. The results of these studies indicate considerable variability. As an example, exhalation rates measured using the accumulator method ranged from 0.33 to 70.6 Bq/m^2-s (MacLaren, 1978b) and from 0.1 to 11.2 Bq/m^2-s (DSMA Atcon, 1985). Based on work by DSMA, it was concluded that accumulators are not an appropriate measurement technique.

The DSMA Atcon study also concluded there was no significant differences between the radon emanation rates from the vegetated or unvegetated uranium tailings areas. Thus, a large fraction of the radon produced in the upper few centimeters of the tailings will escape to the atmosphere, regardless of whether the surface is vegetated or not.

I.5.3.B RADON EMANATION, SASKATCHEWAN

Radon flux measurements have been conducted at Key Lake. The results are summarized in Table I.5.B-3.

I.5.4.A SETTLEMENT AND CRACKING, ONTARIO

Surficial cracking due to desiccation of the slimes material has taken place at most of the tailings sites. Cracks up to 0.3 m deep have been observed (Vivyurka, 1986). Shallower cracks have also been observed in the vicinity of vegetation (Chakravatti, 1986).

No distinct settlement of the tailings has been observed.

TABLE I.5.A-1

RADON EMANATION, ELLIOT LAKE

TAILINGS AREA	SURFACE LOCATION OF SAMPLE	RADON EMANATION (mBq/m^2-s)		REFERENCES
		AERODYNAMIC	ACCUMULATOR	
Denison	Tailings	-	4,700**	MacLaren, 1978b
Williams Lake	Vegetated	-	700*	MacLaren, 1978b
Stanrock	Tailings	-	220*	MacLaren, 1978b
Quirke	Tailings	-	29,800**	MacLaren, 1978b
Nordic	Tailings	-	8,700**	MacLaren, 1978b
	Tailings	3,710**	4,490**	DSMA Atcon, 1985
	Vegetated	4,140*	1,440**	DSMA Atcon, 1985

* one reading
** average

TABLE I.5.B-3

RADON EMANATION FROM TAILINGS

KEY LAKE

SURFACE LOCATION OF SAMPLE	RADON EMANATION (Bq/m^2-s)
WET AREA	2.1
DRY AREA	0.004

(from Knight and Piesold Ltd., 1985)

I.5.4.B SETTLEMENT AND CRACKING, SASKATCHEWAN

All of the tailings sites exhibit surface cracking where fines are present. The desiccated surface layer is thin and generally less than a few tens of millimetres in thickness. It is easily broken up by mechanical weathering. Patterned cracking resulting from shrinkage and frozen ground was obvious in photographs published by Whiting et al (1982).

I.5.5.A FROST HEAVES AND BOILS, ONTARIO

No evidence of frost action in the form of heaves or boils has been observed in the Elliot Lake area.

I.5.5.B FROST HEAVES AND BOILS, SASKATCHEWAN

The climate, groundwater regime, and gradation of the tailings provide an ideal opportunity for development of segregated ice lenses within the tailings both during deposition and after abandonment. Ground ice was reported in tailings at Rabbit Lake (GMCL, 1981). Whiting et al (1982) illustrate development of palsa-type features in the Gunnar tailings, and reported ground ice under the Lorado tailings. The palsa features consisted of a raised mound of tailings, elevated above the surrounding surface. This elevated surface, apparently caused by frost, is prone to wind erosion.

I.5.6.A SHEET AND GULLY EROSION, ONTARIO

Gully erosion has taken place where concentrated flows are present. Locations where concentrated flows have resulted in gully erosion are generally close to the tailings discharge points and where water has, on occasion, over-flowed due to blocked decants. For the most part gullies are 10 to 20 mm deep. However, some are in the order of 0.3 m deep with an invert gradient of 1%.

Sheet erosion has not been observed to be a major form of instability of the tailings. However, some erosion has been observed at the Stanrock site where the dams are comprised of cycloned tailings and downstream slopes are relatively steep.

I.5.6.B SHEET AND GULLY EROSION, SASKATCHEWAN

Water erosion is reported on the abandoned tailings and on retention structures at the active sites. As discussed earlier, substantial water erosion of the Gunnar tailings has taken place, transporting additional tailings to Langley Bay. Continuing erosion, both of the sheet and gully type, is also reported at the Lorado site. Wave erosion of the tailings was also noted. Erosion of tailings into Nero Lake is continuing at a rapid rate. Whiting et al (1982) report an observation by Horn-Johnson that "runoff from the tailings pile during a rainstorm was impressive."

Sheet erosion of the earth dams is reported at Cluff Lake (Amok Ltd., 1985) and Rabbit Lake (Eldorado Resources Limited, 1984). The extent of erosion is relatively minor with silt being eroded from the downstream slope of the

dykes and deposited at the toe. Stabilizing procedures included hydroseeding to establish vegetation on the slopes.

I.5.7.A INFILTRATION, ONTARIO

The rate of infiltration is highly dependent on the surface characteristics of the tailings site. Therefore, representative values can only be determined on a site specific basis. Work carried out by MacLaren and Golder, 1981a, determined the ratio of runoff on tailings to total precipitation to be 0.76. McInnis, 1985, reports that Kilborn in their modelling of the Elliot Lake area assumed a 0.7 ratio of runoff to precipitation. Pullen & Davis, 1981, estimate 350 mm of rainfall per year in the Elliot Lake area runs off directly as surface water.

I.5.7.B INFILTRATION, SASKATCHEWAN

Substantial infiltration is expected considering that the tailings should act as a surficial aquifer. The proportion of precipitation which infiltrates the ground surface was indirectly estimated by the University of Saskatchewan (Amok Ltd., 1985). They found that approximately 60 percent infiltration through the cover must be assumed in model studies to establish reasonable piezometric levels. Others suggest that the rate of runoff is higher: Knight and Piesold Ltd. (1985) estimate that 70% of precipitation on the tailings runs off. Observations at Lorado also suggest the runoff coefficient is high.

I.5.8.A ACID GENERATION AND LEACHING, ONTARIO

Tailings in the Elliot Lake area contains approximately 6% pyrite. Oxidation of this pyrite produces the tailings pore water that have low pHs and high concentrations of iron, heavy metals and some radionuclides. Work carried out by Golder Associates Ltd. (1981g and 1981h) and subsequently published by Feenstra et al, 1981, indicates evidence of oxidation to depths generally in the order of 3 to 4.5 m below the tailings surface. The depth of oxidation is dependent on the gradation of the tailings. Where slimes are present, oxidation occurs only to depths of 1.5 m, whereas in sands, oxidation reaches 4.5 m.

Acid generation and/or seepage is ongoing at each tailings site in Elliot Lake. Recent increased amounts of neutralization materials suggest that either revegetation programs have not helped to reduce acid generation or the water level is decreasing in the ponds.

In an experiment to study underwater disposal of tailings, Rio Algom (Moffet, 1981) filled a pit with pyritic tailings and covered it with 1.5 m of water. During the 5 year test, it was found that no acid generation had taken place. Results of this work therefore favoured underwater disposal of tailings.

I.5.8.B ACID GENERATION AND LEACHING, SASKATCHEWAN

Data reported in sections I.3.1.B, I.3.2.B and I.3.4.B indicate that the sulphide-rich tailings at Lorado are strongly acid generating. Kalin

(1981) reported the pH of Nero Lake to be 3.5, a result of acid discharge during milling, and ongoing acidic seepage.

Some sectors of the Gunnar tailings (Table I.3.B-15) also have low pH pore water. Substantial buffering apparently occurs through the natural soils.

Acid generation studies have been reported for tailings at Cluff Lake, Key Lake and Collins Bay B-Zone. In all cases, the natural acid generating capacity was deemed to be less than the combined natural buffering capacity plus the lime added during tailings conditioning.

I.5.9.A UPWARD SALT MIGRATION, ONTARIO

Where the surface of the tailings is free of water, evidence of upward salt migration is present. Observations indicate salt deposition approximately 300 mm below the tailings surface. In some instances salt deposits have also been observed on the downstream sides of some of the early porous dams. These deposits generally occur where ground water has intersected the downstream slope of the dam.

I.5.9.B UPWARD SALT MIGRATION, SASKATCHEWAN

Accumulations of white salt were reported on the surface of both the Gunnar and Lorado tailings (Kalin, 1981). The precipitate was not identified at Gunnar but, at Lorado, was thought to be magnesium sulphate.

I.5.10.A SEEPAGE, ONTARIO

Every dam retaining saturated tailings in the Elliot Lake area is prone to seepage. Prior to 1970, the dams were generally comprised of waste rock or tailings. In several instances, substantial seepage was observed through these dams. Since 1970, most of these dams have either been replaced or remedial measures have been taken to control the situation. Dams constructed since that time are relatively impermeable and are comprised of a till core and granular shells and contain drainage control zones (filters, etc.). Seepage is still evident. However, it is considered to be within acceptable limits from a stability viewpoint.

I.5.10.B SEEPAGE, SASKATCHEWAN

The seepage reporting to the downstream toe drain at the Cluff Lake mining area is carefully monitored (Amok Ltd., 1985). Direct measurement of seepage volume is made as well as calculations of seepage volume based on changes in water quality in Snake Lake.

The conclusion is that radionuclides are being attenuated both in the retention structure and natural materials and that most seepage through the toe drain is reporting through an imperfection in the soil-bentonite seal.

The construction of the Key Lake tailings management area allows direct monitoring of total flow from the underdrains (KLMC, 1984; Knight and Piesold Ltd., 1985). The flux is estimated to be approximately 463 m^3/day through the underdrains and 50 m^3/day through the underseal (Knight and

Piesold Ltd., 1981a). During mine startup, excessive water storage resulted in flows as high as 58,000 m^3/month through the underdrainage system during the period of October to December 1983 and a total flow of 98,000 m^3 in 1984, with flows ranging from 0 to 35,000 m^3/month (KLMC, 1984, 1985b).

Seepage from the Rabbit Lake tailings area has been quantitatively addressed but is more difficult to quantify. GMCL (1981) reported seepage through relatively pervious dams and in the spring above Parks Lake. The interconnection of the spring through the tailings area was evident in elevated sulphate and common ions, but radionuclides had not yet reported. The seepage through the southerly tailings dam was directed by gravity through the secondary treatment system. Seepage through the northerly tailings dam was monitored and, if necessary, was returned to the pond.

I.5.11.A TRAFFICABILITY, ONTARIO

In general, most tailings sites at Elliot Lake can be traversed on foot except close to the head ponds and discharge areas. Work on the tailings, however, is carried out by wide track equipment. Experience has shown the tailings can easily liquify.

I.5.11.B TRAFFICABILITY, SASKATCHEWAN

The abandoned tailings site at Gunnar and Lorado are trafficable on foot and with light vehicles during the summer months. A conventional truck mounted drill was used to explore the tailings during the summer of 1981 (Whiting et al, 1982).

Mass discharged tailings can be expected to have much lower trafficability. The Rabbit Lake tailings were judged to be untrafficable during summer and only accessible to light vehicles when the crust was frozen (GMCL, 1981). The tailings discharged in thin lifts at Key Lake were untrafficable in the impoundment bottom (Knight and Piesold Ltd., 1985) but trafficability was reportedly greatly improved following winter freezing and subsequent spring thaw.

I.5.12.A WATER BALANCE, ONTARIO

To date, the only time where the balance of free water has been a problem in the area is when decant systems have failed or become blocked. In these instances, impoundments have flooded and in some cases overtopped small embankments.

To better appreciate the existing water surplus in Elliot Lake, a water balance has been prepared for a generic tailings pond typical of the Elliot Lake area. This balance is based on the water budget prepared in Section I.2.2.A and a project water loading from the mine, as described below. It has been assumed that the mine is contributing 1.3 million tonnes of slurry per year. The slurry is assumed to be 30% solids. This loading is equivalent to 910,000 m3/annum of water. The generic tailings pond is assumed to be 160 ha in size. Hence, the average discharge of water to the pond from the mine is the equivalent of 47.4 mm of precipitation per month.

Table I.5.A-2 has been prepared to show the effect of the slurry on the water balance of a tailings pond at Elliot Lake. It shows that the pond has a water surplus of approximately 953 mm per average year. The mine contributes the equivalent to 569 mm of precipitation, which is approximately 8% more water than evapotranspiration removes during an average year.

I.5.12.B WATER BALANCE, SASKATCHEWAN

Detailed design water balances have been conducted for the Cluff Lake, Key Lake and Collins Bay tailings areas. These have been supplemented by measurements during operation at Cluff Lake and Key Lake. Detailed modelling has also been undertaken at all of the active tailings sites. The expected seepage losses range from 50 m^3 per day at Key Lake to 500 m3 per day at Cluff Lake and approximately 500 m^3 per day at Rabbit Lake (Knight and Piesold Ltd, 1981a; W.A. Meneley Consultants Ltd., no date; Geocon Ltd. 1982a).

I.5.13.A SURFACE WATER QUALITY, ONTARIO

Water discharged from each impoundment into the Serpent River Basin is treated with lime and/or barium chloride. Water quality data are monitored by both the mining companies and the Ontario Ministry of the Environment to ensure discharged waters comply with either Provincial surface water guidelines and/or Federal mining discharge effluent quality.

In general, water from the treatment plants have pHs that range from 7 to 8.5. The radiochemical and heavy metal content of the discharge are within those concentrations specified in the mine's operating license.

The surface water discharge in the Elliot Lake area, through stricter government controls and efforts by the various mines, appears to be within specified guidelines. Table I.5.A-3 summarizes the surface water discharge from both Rio Algom and Denison Mines for 1985.

I.5.13.B SURFACE WATER QUALITY, SASKATCHEWAN

The naturally occurring surface water is extremely high quality at all the mines. Typical values for Lake Athabasca, the Douglas River, Gerald Lake and Collins Bay at Wollaston Lake are given in Table I.5.B-4.

TABLE I.5.A-2

TAILINGS POND WATER BALANCE, ELLIOT LAKE AREA

MONTH	WATER BUDGET SURPLUS (mm)	INFLOW FROM MINE (mm)	WATER BALANCE (mm)
JAN	59.3	47.4	106.7
FEB	62.1	47.4	109.5
MAR	58.1	47.4	105.7
APR	63.5	47.4	110.9
MAY	7.1	47.4	54.5
JUN	-33.6	47.4	13.8
JUL	-66.1	47.4	-18.7
AUG	-31.4	47.4	16.0
SEP	50.9	47.4	98.3
OCT	39.1	47.4	86.5
NOV	107.2	47.4	154.6
DEC	68.1	47.4	115.5
TOTAL	384.5	568.8	953.3

TABLE I.5.A-3

TYPICAL SURFACE WATER QUALITY, ELLIOT LAKE AREA

PARAMETER concentrations in mg/L unless noted	RIO ALGOM Q-3	DENISON D-2
TIME (average of year)	1985	1985
FLOW (L/s)	185	247
pH	8.0	8.2
ACIDITY as CaCO3	46	22
ALKALINITY as CaCO3	40	46
TOTAL SUSPENDED SOLIDS	9	4
TOTAL DISSOLVED SOLIDS	2878	2768
SULPHATE	1573	1370
DISSOLVED RADIUM 226 (pCi/L)	2.5	2.2
TOTAL RADIUM 226 (pCi/L)	4.1	33.2
LEAD	0.034	<0.04
ZINC	0.033	0.01
NICKEL	0.054	0.03
COBALT	0.056	0.05
IRON	6.9	0.33
MANGANESE	0.72	0.21
COPPER	0.022	0.01
MAGNESIUM	16.5	18
CALCIUM	582	467
NITRITE as N	0.94	6.1
NITRATE as N	69	87
AMMONIA as N	44	49
TOTAL NITROGEN as N	47	11
URANIUM U_3O_8	0.49	0.08
PHOSPHORUS	0.032	0.04
CHLORIDE	16	119
POTASSIUM	N/A	37
BARIUM	N/A	<0.25
SODIUM	N/A	91

After Vivyurka, 1986 & Laliberte, 1986

TABLE I.5.B-4

TYPICAL SURFACE WATER QUALITY, SASKATCHEWAN

	DOUGLAS RIVER	GERALD LAKE	COLLINS BAY	LAKE ATHABASCA
Year	1976	1977	1978	1978
pH	7.52	6.90	6.67	7.0-7.4
Cond ($umho/cm^2$)	131		15.70	60-135
$O\text{-}PO_4$	<0.01	0.06	<0.01	
$T.PO_4$	0.06	0.07	<0.02	<0.01-0.01
TKN	0.216		0.15	0.26-0.41
NH_3	0.058	0.02		<0.01-0.03
NO_3	0.001	0.005	0.04	<0.01-0.13
TDS	85	54.0	30	
TSS	1.3	4.0	1.4	<1-8
SO_4	<1	<1.0	3.04	<5-8
CL	22	<1.0	0.51	0.6-3.8
HCO_3	31	8.1		
CO_3	0.0	0.0	5.3	
Ca	12	0.71	2.6	7-8
Na	4.0	1.25	0.83	2-3
Mg	6	0.21	0.85	2
K	1.0	0.71	2.7	0.7-0.9
D. Ra_{226}		<0.1 pCi/L	nil	0.1 pCi/L
T. Ra_{226}	<0.1 pCi/L	<0.1 pCi/L	nil	<0.1-0.2 pCi/L
U	0.0001 pCi/L	<0.0005 pCi/L	0.0003	0.003
Pb_{210}	0.5 pCi/L	0.10 pCi/L	nil	<0.5-1.4 pCi/L
Po_{210}	<0.1 pCi/L	<0.1 pCi/L	nil	
Th_{230}	0.001 pCi/L	<0.7 pCi/L	nil	<0.3-0.9 pCi/L
Ag			<0.01	
Al			0.19	
As	<0.001	<0.0005	<0.01	<0.005
Ba	<0.02	0.005	<0.1	
Bi			<0.2	
Cd	<0.001	<0.0005	<0.005	<0.002
Co	<0.001		<0.1	
Cr	<0.005	0.017	<0.01	
Cu	<0.001	<0.001	<0.005	<0.02
F		0.076		
Fe	0.25	0.042	2.1	<0.03-0.08
Hg	<0.0005	<0.00005	<0.00001	
Mn	0.01	0.002	<0.03	
Mo			<0.01	
Ni	0.002	<0.001	<0.01	<0.03
Pb	0.002	0.003	<0.01	<0.005
Se	<0.005	<0.002	0.02	
V		<0.01	<0.005	
Zn	0.004	0.005	<0.005	<0.01

Note: pH is reported in standard units; all other parameters are in mg/L except where noted.

(from Stearns-Roger Incorporated, 1976; Stevenson Int. Groundwater Consultants Ltd., 1978; Gulf Minerals Canada Limited, 1980; Ruggles et al, 1978)

I.6.0 CONSTRUCTION PRACTICES

I.6.1.A SITE SELECTION, ONTARIO

In the 1950s and 60s, the main criteria for site selection of tailings impoundments were to locate the depression closest to the mill, which was on the mine's property. Since the 1970s, however, the site selection process carried out by mines has become quite extensive. J.F. MacLaren and H.Q. Golder, 1979b, describe the scope of these studies. The following paragraphs outlining specific guidelines and selection criteria are abstracted from their report.

The criteria developed for the selection of a tailings impoundment site are summarized in Table I.6.A-1. By following through this set of criteria for several alternative sites, the most appropriate impoundment site is chosen.

I.6.1.B SITE SELECTION, SASKATCHEWAN

The first generation mines (Gunnar, Lorado and Beaverlodge) were built prior to formulation of regulations to control waste discharges. The tailings sites were located to give the most economic, trouble-free discharge.

The second generation mines, beginning with development of the Rabbit Lake Mine, were initially subject to the provisions of the Pollution Prevention Regulations For The Mineral Industry, 1970, under the Mineral Resources Act. The proposal to develop the Cluff Lake ore bodies resulted in establishment of the Cluff Lake Board of Inquiry under the Department of Environment Act (1978). This inquiry examined the provincial regulatory framework and recommended revisions to the licensing and regulation of uranium mining and milling. All subsequent developments have been subject to provisions of the Atomic Energy Control Board of Canada and Saskatchewan Environment. Pertinent regulations include:

- AECB Document 23D, facilities for retention of uranium mine mill wastes.
- AECB Document 31, guide to the licensing of uranium and thorium mine mill facilities.
- The Saskatchewan Environment Act and regulations published thereunder.
- The Saskatchewan Environmental Impact Assessment Act.

The requirements for site selection under these regulations are not strictly defined, but, to some degree, are left to negotiations based on site specific conditions. The site selection criteria commonly include:

- Seismic and tectonic stability;
- Controls on pollution of surface water;
- Controls on pollution of groundwater;
- Air pollution controls;
- Physical stability;

TABLE I.6.A-1

CRITERIA FOR SELECTION OF A TAILINGS IMPOUNDMENT SITE, ELLIOT LAKE

Criteria Grouping		Criteria
I.	Common Factors	- characteristics of tailings - climatic conditions - seismic stability - legislation
	Remarks:	- general characteristics of a tailings impoundment site can be considered, e.g. land or deep water
II.	Preliminary (General) Criteria	- quantity of tailings to be deposited - proximity of site to mill - proximity to townsite - topography of area
	Remarks:	- potential sites can be identified
III.	Detailed Criteria	
	1) Effect on Environment	- Surface water pollution potential - ground water pollution potential - potential effect on vegetation, wildlife and aquatic life - existing use of area
	2) Development and Maintenance Costs	- capital costs for development - cost of transporting tailings - operating costs - requirements for isolation from surrounding watershed - accessibility - availability of construction materials
	Remarks:	- final site selection

Guidelines and regulations currently applicable to the development of site selection criteria in Elliot Lake are:

- AECB 23D, Facilities for Retention of Uranium Mine-Mill Wastes
- AECB 31, Guide to the Licencing of Uranium and Thorium Mine-Mill Facilities
- MOE, Tailings Disposal, Recommendations for Site Selection 1976
- MNR, Guidelines and Criteria for Approvals under the Lakes and Rivers Improvement Act, March 1977.

- Requirements to consider social and economic impact;
- Consideration of impacts in both operating and decommissioned phases; and,
- Requirements for monitoring and mitigation of impacts.

The detailed criteria are site specific and generally include:

- Minimization of surface area to be disturbed;

- Siting to minimize effect of surface runoff and erosion, preferably by minimizing the amount of surface water that must be diverted or handled;

- Locating as far from a main watercourse as possible, preferably far up on a tributary to the main drainage system in the basin;

- Ability to be suitably monitored;

- Siting to enable implementation of suitable mitigative measures;

- Construction materials that are chemically and physically stable to contain wastes in the very long term; and,

- Locating in a socio-economically acceptable location.

I.6.2.A CONSTRUCTION MATERIALS, ONTARIO

The tailings impoundments dykes at Elliot Lake until the 1970s were generally comprised of waste rock, sand and gravel, and/or cycloned tailings. Based on a geotechnical review of the existing dams and stricter government regulations, dams constructed after this date have generally been comprised of compacted till cores with sand and gravel shells.

The till is generally placed and compacted in lifts of 300 mm. The top of each lift is subsequently scarified to ensure proper bonding between lifts. Compaction to the required 95% Standard Proctor density is achieved using either a pneumatic tired roller or a smooth drum roller (Reades et al, 1982).

Filter zones, comprised of sands and gravel, are generally placed in lifts up to 500 mm. The required compactive effort, using a vibratory drum roller, is also 95% of the appropriate Standard Proctor density.

The shells of the dams are constructed of till, sand and gravel, or coarse tailings. Reades et al, 1982, and H.Q. Golder and Associates Ltd., 1980c, report lift thicknesses are between 300 and 500 mm, compacted to 95% of the Standard Proctor maximum dry density. Depending on the composition of the material, either a vibratory drum roller or smooth drum roller is used.

A summary of the characteristic properties of these materials is provided in Table I.6.A-2.

Waste rock has been used as drain material, rip rap, fill for dyke construction and, in the case of the earlier dams, as embankment fill. The

TABLE I.6.A-2

PHYSICAL PROPERTIES OF LOCAL CONSTRUCTION MATERIALS, ELLIOT LAKE

PHYSICAL PROPERTIES		SILT TILL	SAND & GRAVEL
GRADATION (% by weight)	GRAVEL	10-40%	5-50%
	SAND	35-50%	45-95%
	SILT	20-30%	0-20%
	CLAY	5-10%	-
SPECIFIC GRAVITY		2.67	2.64
IN SITU WATER CONTENT		8-9%	-
ATTERBERG LIMITS	Liquid Limit	14	N/A
	Plasticity Index	2	N/A
COMPACTION CHARACTERISTICS (STANDARD PROCTOR)	Water Content	8%	11%
	Dry unit weight	20.6 kN/m^3	18.1 kN/m^3
EFFECTIVE SHEAR STRENGTH			
	Angle of Internal Friction	37 degrees	35 degrees
	Cohesion	0 kPa	0 kPa
DYNAMIC STRENGTH Kc=1 (cyclic stress for failure at 6 cycles)		0.35	0.36
HYDRAULIC CONDUCTIVITY (m/s) (Compacted)		10^{-6} to $4x10^{-10}$	-
CONSOLIDATION CHARACTERISTICS			
	Compresssion Index	.04-0.05	-
	Coefficient of Consolidation	0.2-0.1 cm^2/s	-

(After Reades et al, 1982, & H.Q. Golder and Associates Ltd., 1980a and Golder Associates Ltd., 1981)

waste rock in the Elliot Lake area is generally well graded, angular, competent material with rock fragment diameters in the order of 250 mm. Grain size analyses carried out by Golder Associates Ltd., 1981i, on minus 19 mm material indicate the matrix of the material is comprised of sand and gravel with traces of silt. H.Q. Golder and Associates Ltd., 1978c, indicates that the matrix is approximately 15 per cent by weight of the waste rock.

I.6.2.B CONSTRUCTION MATERIALS, SASKATCHEWAN

Typical properties and density specifications for materials used for the Cluff Lake, Key Lake and Rabbit Lake embankment are given in Table I.6.B-1, -2 and -3, respectively.

I.6.3.A EMBANKMENTS, ONTARIO

There are a variety of dams constructed in the Elliot Lake district. These include water diversion dykes, tailings dams and concrete wing walls. Dams built prior to 1970, generally are comprised of permeable materials such as waste rock and/or tailings. These dams were typically constructed on the existing ground surface with no special precautions taken for foundation treatment. Since then, zoned dams comprised of thick till cores and wide granular supporting shells have been constructed. In some cases upstream Hypalon liners and/or central concrete core walls have been incorporated into the design. Typical profiles of dams at Denison Mine and Rio Algom properties are shown on Figures I.6.A-1 and I.6.A-2, respectively.

Foundation preparation has also changed over the years at Elliot Lake. In general, the cores of most dams are founded on bedrock and the shells are supported on either bedrock or the overburden materials. In each case the foundation is cleared and stripped of organics. Where the core is founded on bedrock, foundation treatment consists of a combination of blanket and curtain grouting to reduce seepage. Grout curtains are generally constructed to 12 m depths or equivalent to the maximum height of the dam. Rodgers et al, 1982, reports the primary grout hole pattern is on a 6.1 m spacing with secondary, tertiary and quaternary grouting at a reduced split spacing, as required, to achieve lateral closure of the grout curtain. Blanket grouting is normally extended to 5 m below surface. In addition to the above grouting program, the foundation surface is treated with either dental concrete, shotcrete and/or slush grout. In all cases, due to the acidic porewater chemistry of the tailings, sulphate resistant cement is used (Reades et al, 1982). Rogers et al, 1982, reports the mass permeability of the rock is typically 10-7 m/s after grouting.

In 1977 and 1978, Golder Associates were retained to review the stability and seepage aspects of the existing dams and dykes at the Rio Algom and Denison properties (H.Q. Golder, 1978a and 1978e). Based on these studies and subsequent geotechnical investigations, several of the early permeable dams have been repaired or replaced. In the case of the Stanrock and Williams Lake dams, downstream berms were constructed to increase their stability. At Stanleigh Mine tailings area, piping was evident through the existing dam. To control this, a stabilizing berm was constructed along its downstream toe. This dam has been recently replaced by Dam A, which was constructed immediately downstream of the existing dam.

TABLE I.6.B-1

PROPERTIES OF CLUFF LAKE EMBANKMENT MATERIALS

PHYSICAL PROPERTIES		TILL
GRADATION (% by weight)	Gravel	18-59
	Sand	21-74
	Silt and Clay	8-20
SPECIFIC GRAVITY		2.63
IN SITU WATER CONTENT		8-10
ATTERBERG LIMITS	Liquid Limit	NP
	Plasticity Index	NP
COMPACTION CHARACTERISTICS (Modified Proctor)	Water content (%)	9
	Dry Unit Weight (Mg/m^3)	2.00
EFFECTIVE SHEAR STRENGTH		
Angle of internal friction (degrees)		37.5
Cohesion (kPa)		0
HYDRAULIC CONDUCTIVITY (m/s) (compacted)		$0.05\text{-}1.7 \times 10^{-6}$
CONSOLIDATION CHARACTERISTICS		
Compression index		no data
Coefficient of Consolidation		no data

(from Geocon Inc., 1980d)

TABLE I.6.B-2

PROPERTIES OF KEY LAKE EMBANKMENT MATERIALS

PHYSICAL PROPERTIES		TILL	SAND
GRADATION (% by weight)	Gravel	21	0
	Sand	68	96
	Silt and Clay	11	4
SPECIFIC GRAVITY		no data	no data
IN SITU WATER CONTENT (%)		8+/-	no data
ATTERBERG LIMITS	Liquid Limit	NP	NP
	Plasticity Index	NP	NP
COMPACTION CHARACTERISTICS (Standard Proctor)	Water content (%)	8	no data
	Dry Unit Weight (Mg/m^3)	2.00	1.77
EFFECTIVE SHEAR STRENGTH			
Angle of internal friction (degrees)		41.5	no data
Cohesion (kPa)		0	no data
HYDRAULIC CONDUCTIVITY (m/s) (compacted)		no data	$.18\text{-}1.4X10^{-4}$
CONSOLIDATION CHARACTERISTICS			
Compression index		no data	no data
Coefficient of Consolidation		no data	no data

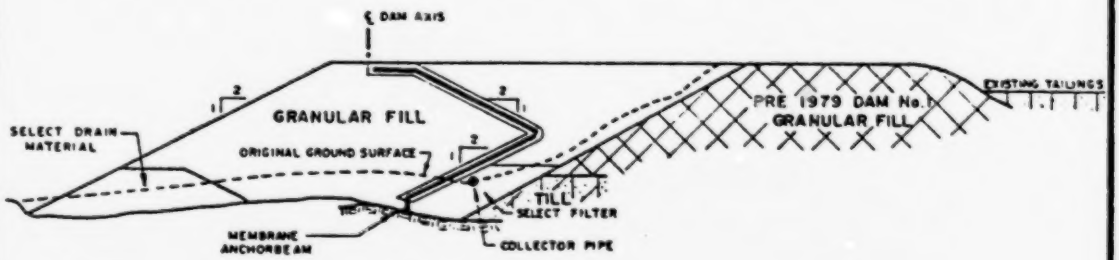
(from Knight and Piesold Ltd., 1981, 1984a)

TABLE I.6.B-3

PROPERTIES OF RABBIT LAKE EMBANKMENT MATERIALS

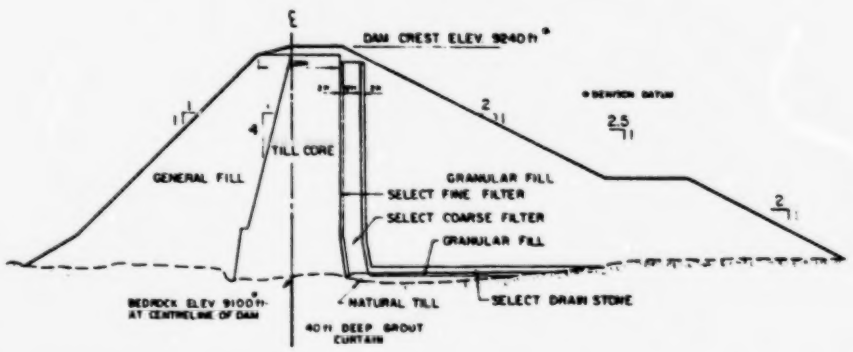
PHYSICAL PROPERTIES		CYCLONED TAILINGS	SILTY TILL	SANDY TILL
GRADATION (% by weight)	Gravel	0	14-31	20-27
	Sand	79	27-61	47-66
	Silt and Clay	21	19-43	10-30
SPECIFIC GRAVITY		2.54	no data	no data
IN SITU WATER CONTENT		no data	no data	no data
ATTERBERG LIMITS	Liquid Limit	NP	no data	no data
	Plasticity Index	NP	no data	no data
COMPACTION CHARACTERISTICS (Modified Proctor)	Water Content (%)	15	6.0-6.7	5.5-6.1
	Dry Unit Weight (Mg/m^3)	1.83	2.13-2.20	1.99-2.15
EFFECTIVE SHEAR STRENGTH				
Angle of internal friction (degrees)		33-38	no data	no data
Cohesion (kPa)		0	no data	no data
HYDRAULIC CONDUCTIVITY (m/s) (compacted)		no data	no data	no data
CONSOLIDATION CHARACTERISTICS				
Compression index		no data	no data	no data
Coefficient of Consolidation		no data	no data	no data

(from Geocon Inc. 1973, 1980a, 1981, 1982b, 1984a)



WILLIAMS LAKE, Dam 1

(After Reades et. al, 1981)



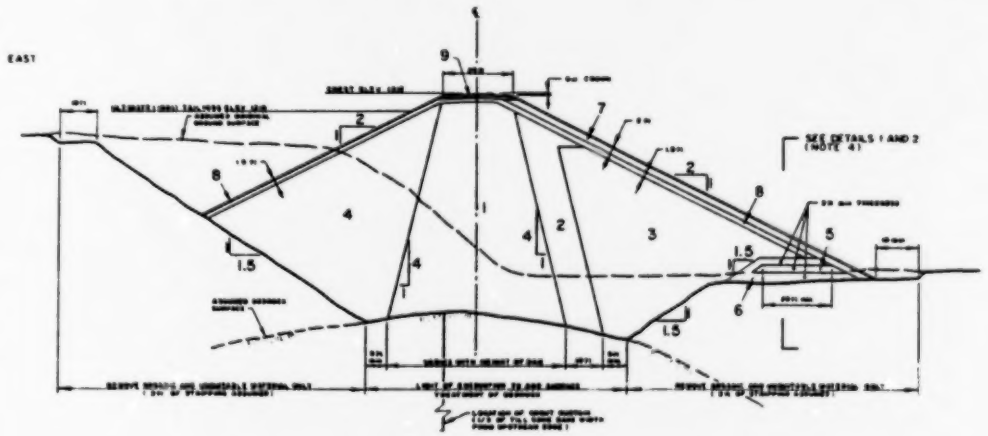
DENISON MINE, Dam 17

(After Reades et. al, 1982)

NOT TO SCALE

TYPICAL DAM PROFILES

FIGURE I.6.A-1

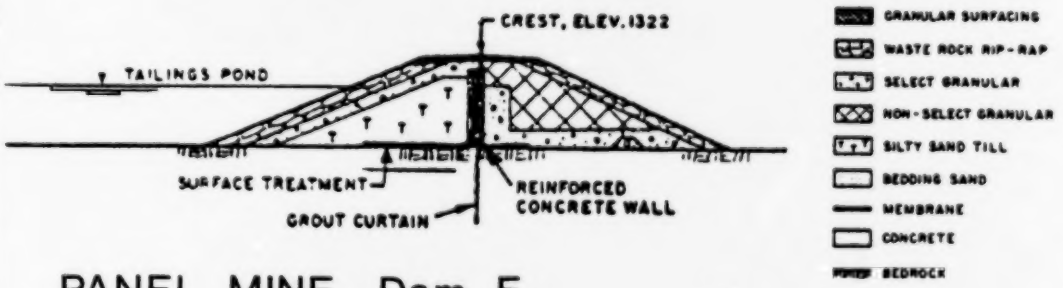


QUIRKE, Dam K

LEGEND

1. CORE - GLACIAL TILL
2. FILTER - PROCESSED SAND
3. DOWNSTREAM SHELL - SAND AND GRAVEL
4. UPSTREAM SHELL - TAILINGS SAND
5. DRAIN - PROCESSED GRAVEL
6. FILTER - PROCESSED COARSE SAND
7. EROSION PROTECTION - COBBLES
8. BEDDING / EROSION PROTECTION - SELECT SAND AND GRAVEL
9. ROAD SURFACING - GRAVEL

(After Golder, 1981)



PANEL MINE, Dam F

(After Pullen & Davis, 1981)

NOT TO SCALE

TYPICAL DAM PROFILES

FIGURE I.6.A-2

Reades et al, 1982, report containment dams in Elliot Lake are designed to withstand the effects of the maximum credible earthquake. The seismic risk at Elliot Lake using a deterministic procedure was determined by Weston Geophysical Research, Inc. who recommended that the design earthquake (hypothetical) be taken as a Magnitude 6.5 event located 230 km from Elliot Lake, in the Western Quebec zone. It was predicted that this design event would cause an upperbound of Intensity VI (MM) at Elliot Lake with a corresponding peak horizontal ground acceleration of 0.065 g for average foundation conditions, a duration of shaking of less than 20 seconds and predominant frequencies between 1 and 4 Hz.

I.6.3.B EMBANKMENTS, SASKATCHEWAN

The Lorado and Gunnar facilities were non-engineered sites where containment was not a consideration. By comparison, environmental criteria became progressively more stringent as the Rabbit Lake, Cluff Lake, Key Lake and Collins Bay B-Zone facilities were constructed. As a consequence, material selection, design and quality control were major considerations.

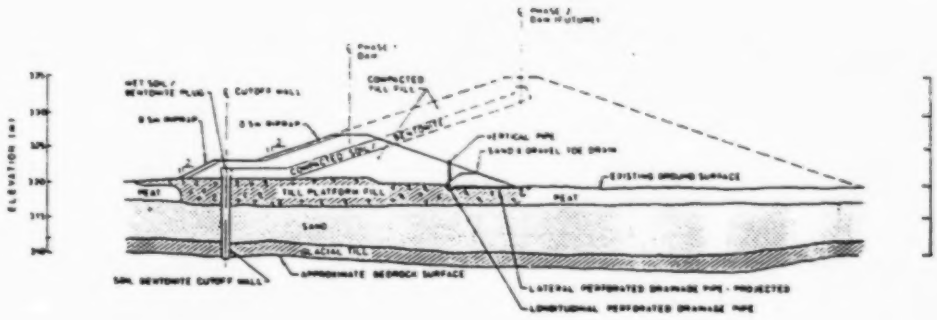
Typical cross sections of the containment structures at Cluff Lake, Key Lake, Rabbit Lake and Collins Bay B-Zone are illustrated in Figures I.6.B-1 to -4, inclusive. The sections illustrate the unique utilization of materials in the various structures.

The Cluff Lake structure was constructed by excavating the surficial peat and constructing a soil-bentonite slurry cutoff to the underlying fractured bedrock. The main embankment was constructed of compacted till with a compacted soil-bentonite cutoff. A sand and gravel toe drain and collector system was installed for seepage control.

The Key Lake system (Figure I.6.B-2) was constructed by excavating the natural till and constructing an underseal and intermediate seal of uncompacted soil-bentonite. The underdrain medium was clean outwash sand and compacted sand. Glacial till was used for the embankments.

The Rabbit Lake facility (Figure I.6.B-3) consisted of a north and south dam constructed by excavating the natural peat to underlying till. A starter dam of compacted glacial till was placed with the sand and gravel toe drain. The Phase 1 dam was constructed of cycloned tailings using the downstream method (Geocon Ltd, 1973). The design called for an upstream membrane consisting of a double application of catalytically blown asphalt approximately one quarter inch thick placed on the cycloned tailings face. It cannot be confirmed if this detail was incorporated in the actual construction. The dams were designed for ten years of mill operation but were raised in several stages beginning in 1979, utilizing compacted till. The precipitation ponds were constructed in a similar manner with a deep cutoff excavated a minimum of 20 feet below ground surface. The cutoff and main embankment were constructed of till compacted to at least 95 percent Modified Proctor density. A toe filter of clean sand and gravel was incorporated.

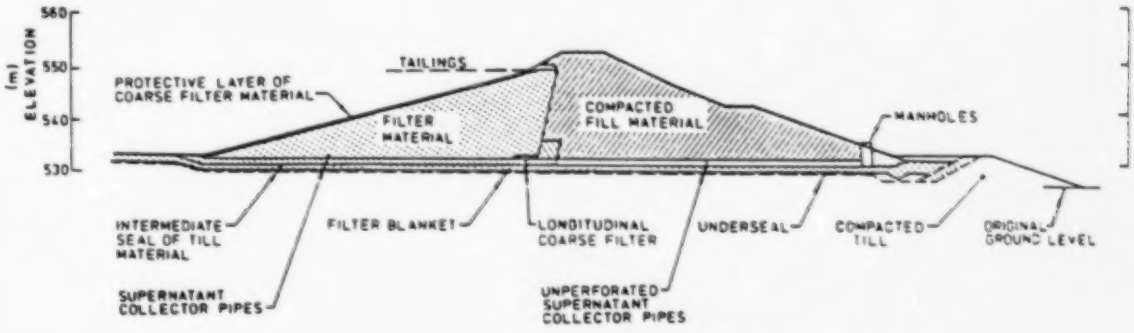
The Collins Bay B-Zone facility utilized the abandoned Rabbit Lake pit. The pit was prepared by constructing a drainage gallery and placing a



NOT TO SCALE

TYPICAL SECTION, CLUFF LAKE SCHEME
(FROM GEOCON LTD., 1980d)

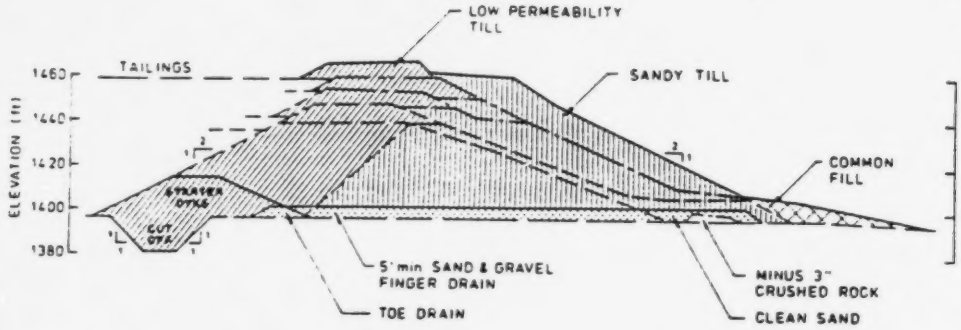
FIGURE I.6. B-1



NOT TO SCALE

TYPICAL SECTION, KEY LAKE SCHEME
(FROM KNIGHT AND PIESOLD LTD., 1981a)

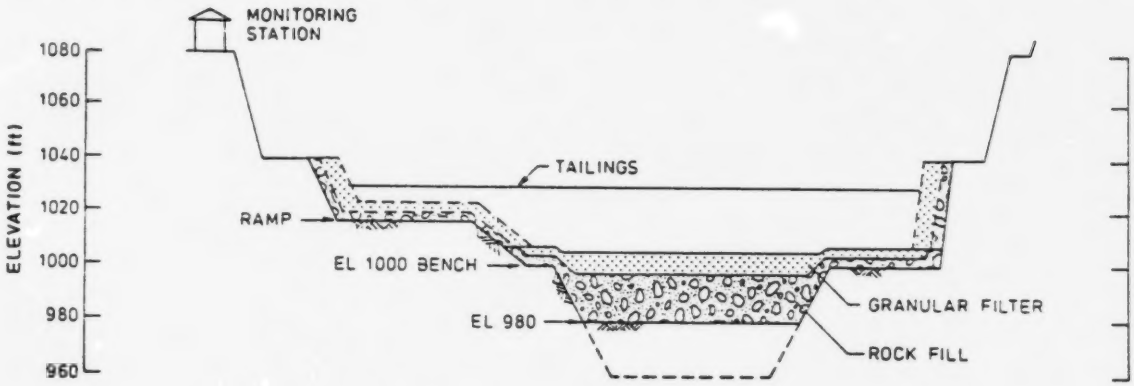
FIGURE I. 6. B - 2



NOT TO SCALE

TYPICAL SECTION, RABBIT LAKE SCHEME
(FROM GEOCON LTD., 1980a, 1981, 1982b, 1984a)

FIGURE I.6.B-3



NOT TO SCALE

TYPICAL SECTION, COLLINS BAY SCHEME
(FROM GEOCON LTD., 1984 b)

FIGURE I. 6. B - 4

perimeter filter called a "pervious surround" (Geocon Ltd., 1984b). A typical cross section of the construction is given in Figure I.6.B-4.

I.6.4.A LINERS, ONTARIO

Hypalon liners have been widely used at the various Elliot Lake tailings sites. They have been used both to line settling ponds and along the upstream side of such major dams as Dam 10, at Denison Mines Tailings Management area, to reduce seepage. To date their performance is considered acceptable.

For the most part, however, natural liners in the form of bedrock or, in the case of the earlier dams, overburden are used. Permeability of the bedrock is dependent on the formation, however the general range is 10-5 to 10-7 m/s. For the overburden materials permeabilities typically are 10-7 m/s for the till and in the range of 10-5 m/s for the granular materials.

I.6.4.B LINERS, SASKATCHEWAN

A variety of liners and seepage barriers were used in the waste management schemes in Northern Saskatchewan. These include:

- Soil-bentonite slurry trench under the containment dyke at Cluff Lake, constructed contiguous with a compacted soil bentonite cutoff through the dyke. Manufactured membrane liners were used in the secondary treatment system precipitation ponds.

- Compacted soil-bentonite liners and cutoffs were used in the Key Lake tailings pond. Manufactured membranes (hypalon) were utilized in the water treatment and watering ponds.

- Sprayed, catalytically blown asphalt was specified for the upstream faces of the cycloned tailings embankment at Rabbit Lake.

Typical specifications, gradations and properties of the natural liner and barrier materials utilized at Cluff Lake and Key Lake are given in Tables I.6.B-4 and -5, respectively.

I.6.5.A UNDERDRAINS, ONTARIO

Underdrains in the form of collector pipes have been installed upstream of the Hypalon membranes to collect seepage. Underdrains are also installed downstream of the Hypalon membranes. Reades et al, 1981 report some precipitate has been noticed in the collector drain at Williams Lake. Analyses indicate the two major mineral phases as limonite and aluminum hydroxide.

I.6.5.B UNDERDRAINS, SASKATCHEWAN

The underdrain materials consist of naturally occurring surficial sand and gravel deposits near the mine sites. Typical specifications and properties of underdrain material from Cluff Lake, Key Lake, Rabbit Lake and Collins Bay B-Zone are given in Tables I.6.B-6 to -9, inclusive.

TABLE I.6.B-4

PROPERTIES OF CLUFF LAKE BARRIER MATERIALS

PHYSICAL PROPERTIES		SOIL-BENTONITE CUTOFF	COMPACTED SOIL-BENTONITE
GRADATION (% by weight)	Gravel	18	no data
	Sand	59	no data
	Silt and Clay	23	no data
SPECIFIC GRAVITY		1.09-1.59	2.67
IN SITU WATER CONTENT (%)		10-12	n/a
COMPACTION CHARACTERISTICS (Modified Proctor)	Water content (%)	n/a	9
	Dry Unit Weight (Mg/m^3)	n/a	2.07
EFFECTIVE SHEAR STRENGTH			
Angle of internal friction (degrees)		no data	0 (assumed)
Cohesion (kPa)		no data	35.8-42.6
HYDRAULIC CONDUCTIVITY (m/s) (compacted)		0.1 to 3.0×10^{-9}	1.2 to 5.5×10^{-9}

(from Geocon Inc., 1980c, 1980d; W.A. Meneley Consultants Ltd., 1979, 1980)

TABLE I.6.B-5

PROPERTIES OF KEY LAKE BARRIER MATERIALS

PHYSICAL PROPERTIES		COMPACTED SOIL-BENTONITE
GRADATION (% by weight)	Gravel	21
	Sand	64
	Silt and Clay	15
SPECIFIC GRAVITY		2.59
IN SITU WATER CONTENT (%)		8-11
ATTERBERG LIMITS	Liquid Limit	no data
	Plasticity Index	0-28
COMPACTION CHARACTERISTICS (Modified Proctor)	Water Content (%)	no data
	Dry Unit Weight (Mg/m^3)	2.05
HYDRAULIC CONDUCTIVITY (compacted)	(m/s)	2.8×10^{-10}

(from Knight and Piesold Ltd., 1984a)

TABLE I.6.B-6

PROPERTIES OF CLUFF LAKE UNDERDRAIN MATERIALS

PHYSICAL PROPERTIES		GRAVEL
GRADATION (% by weight)	Gravel	40-82
	Sand	14-60
	Silt and Clay	0-4
ATTERBERG LIMITS	Liquid Limit	NP
	Plasticity Index	NP
EFFECTIVE SHEAR STRENGTH		
Angle of internal friction (degrees)		36.5
Cohesion (kPa)		0

(from Geocon Inc., 1980c, 1980d)

TABLE I.6.B-7

PROPERTIES OF KEY LAKE UNDERDRAIN MATERIALS

PHYSICAL PROPERTIES		SAND	GRAVEL
GRADATION (% by weight)	Gravel	0	71
	Sand	96	22
	Silt and Clay	4	<5
ATTERBERG LIMITS	Liquid Limit	NP	NP
	Plasticity Index	NP	NP
COMPACTION CHARACTERISTICS (Standard Proctor)	Water Content (%)	no data	no data
	Dry Unit Weight (Mg/m^3)	1.77	1.86
HYDRAULIC CONDUCTIVITY (m/s) (compacted)		$0.18\text{-}1.4 \times 10^{-4}$	1×10^{-3}

(from Knight and Piesold Ltd., 1984a)

TABLE I.6.B-8

PROPERTIES OF RABBIT LAKE UNDERDRAIN MATERIALS

PHYSICAL PROPERTIES		SAND
GRADATION (% by weight)	Gravel	0
	Sand	70-100
	Silt and Clay	0-30

(from Geocon, Inc. 1973)

TABLE I.6.B-9

PROPERTIES OF COLLINS BAY B-ZONE UNDERDRAIN MATERIALS

PHYSICAL PROPERTIES		ROCK FILL	SAND
GRADATION (% by weight)	Gravel	100	no data
	Sand	0	
	Silt and Clay	0	
ATTERBERG LIMITS	Liquid Limit	NP	NP
	Plasticity Index	NP	NP

(from Geocon Inc., 1984b)

I.6.6.A COVERS, ONTARIO

As previously discussed, most of the inactive sites at Elliot Lake have been revegetated or are covered with water. Covers generally are in the form of lime, soil, vegetation, water and/or exposed tailings.

I.6.6.B COVERS, SASKATCHEWAN

None of the subject tailings sites have been reclaimed. Reclamation studies are in progress for all of the active sites. Covers being considered include vegetation, waste rock, till and soil-clay mixtures, or a combination of these types.

I.6.7.A TAILINGS MANAGEMENT, ONTARIO

Details of the various tailings management schemes are discussed in Section I.4.0.

I.6.7.B TAILINGS MANAGEMENT, SASKATCHEWAN

This was previously discussed in Section I.4.0.

I.6.8.A DRAINAGE AND DIVERSIONS, ONTARIO

Drainage from the tailings basins at Elliot Lake have been based on two general principles; 1) the impoundments must contain the Regional storm and 2) must be able to safely pass flows associated with the Probable Maximum Precipitation event.

The Regional storm, as defined by the Ministry of Natural Resources Regulations, is considered to be the Timmins storm where 193 mm of precipitation fell in a 12-hour period. The probable maximum precipitation (PMP) in the Elliot Lake area is 424 mm, in 12 hours. The PMP is considered to lead to the Probable Maximum Flood (PMF), MacLaren & Golder, 1981a.

Drainage works in the early impoundments have generally been comprised of decant systems. These systems have had a very poor track record and in almost all cases have either failed or have been blocked resulting in flooding and in some instances overtopping of the dam. Thus, in recent years these decant systems have been replaced by emergency spillways.

In order to reduce the drainage area and fresh water inflow into the various tailings management areas, diversion systems in the form of berms and rock excavated channels have been constructed. Diversion works have been incorporated extensively into the Quirke, Panel, Stanleigh, Denison and Williams Lake areas.

I.6.8.B DRAINAGE AND DIVERSIONS, SASKATCHEWAN

Presently licensed tailings impoundments must be able to accommodate the design storm both in the pond and in the diversion works. The design storm at Rabbit Lake and Key Lake was taken to be 75 mm in 24 hours (Geocon Ltd., 1973; Knight and Piesold Ltd., 1981a). All of the ponds were designed to

accept this design storm in the watershed when the pond was full of tailings. The Key Lake site is high in the watershed and required nominal diversion work. Similarily, drainage was both north and south from the Rabbit Lake facility requiring little diversion. The Collins Bay B-Zone is protected from inflow to the pit by surface drainage control. Only the Cluff Lake facility requires substantial diversion works in the form of graded ditches to divert surface water around the facility.

I.6.9.A SEEPAGE CONTROL MEASURES, ONTARIO

Seepage control measures incorporated into the design of the various embankments include one or all of the following:

1) Grout Curtains, located both upstream and beneath the centreline of the dam,
2) Hypalon liners,
3) Concrete core walls,
4) granular filters, and/or
5) toe drains.

Based on observation of the performance of the recent structures, these measures are and have been performing well.

I.6.9.B SEEPAGE CONTROL MEASURES, SASKATCHEWAN

This was previously discussed in Section I.6.3.B.

I.6.10.A WATER STORAGE, TREATMENT AND QUALITY CONTROL MEASURES, ONTARIO

Specific details of these systems are discussed for each impoundment in Section I.4.0. In general, seepage from the various impoundments prior to discharging into the Serpent River basin is treated with lime and barium chloride. Water quality is monitored by both the mining companies and the Ontario Ministry of the Environment.

I.6.10.B WATER STORAGE, TREATMENT AND QUALITY CONTROL MEASURES, SASKATCHEWAN

The water treatment and monitoring facilities at each tailings management system were previously discussed in Section I.4.0. All of the active sites have extensive water treatment, monitoring and quality control systems to ensure effluents are of adequate quality for discharge to the environment.

I.6.11.A STABILITY OF THE IMPOUNDMENTS, ONTARIO

The existing and anticipated stability of the various impoundments are summarized in Tables I.6.A-3 to -10. The long-term stability assumes abandonment of the existing impoundment with some form of minimal but appropriate cover in place. The evaluations of future stability are purely subjective evaluations by the authors based largely on projections of present conditions and comparisons with natural land forms. They serve to highlight the modes of long term instability considered most likely by the authors. The assessment of present conditions and future potential for

TABLE I.6.A-3

EXISTING AND LONG TERM STABILITY OF DENISON TAILINGS AREA

MODE OF INSTABILITY	PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS		
SHEET EROSION	m	M
GULLEYING	m	M-s
WIND EROSION	m	M
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION	n	M
DIFFERENTIAL SETTLEMENT	m	m
FROST HEAVE	m	m
INFILTRATION	m - M	M
B. EMBANKMENTS		
SHEET EROSION	m	M
GULLEYING	M	M-s
FLOOD EROSION	n	M
WIND EROSION	m	m
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION/PRECIPITATION	n	m
FROST ACTION - SLOUGHING	N/A	N/A
- UNDERDRAIN BLOCKAGE	N/A	N/A
PHYSICAL INSTABILITY	m	m
PIPING	n	m
C. OTHER STRUCTURES		
LINERS	n	m
DIVERSION WORKS - FLOODS	m	M
- GULLY EROSION	m	M-s
- ICE & DEBRIS BLOCKAGE	m	s
- SEDIMENTATION	m	M-s
SURFACE WATER QUALITY - WITHOUT TREATMENT	s	s
- WITH TREATMENT	m	m
SEEPAGE CONTROL MEASURES	n	m

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occuring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

TABLE I.6.A-4

EXISTING AND LONG TERM STABILITY OF WILLIAMS TAILINGS AREA

MODE OF INSTABILITY	PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS		
SHEET EROSION	m	M
GULLEYING	m	M-s
WIND EROSION	m	M
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION	n	M
DIFFERENTIAL SETTLEMENT	m	m
FROST HEAVE	m	m
INFILTRATION	m - M	M
B. EMBANKMENTS		
SHEET EROSION	m	M
GULLEYING	m	M-s
FLOOD EROSION	m	m - M
WIND EROSION	m	m
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION/PRECIPITATION	n	m
FROST ACTION - SLOUGHING	N/A	N/A
- UNDERDRAIN BLOCKAGE	N/A	N/A
PHYSICAL INSTABILITY	m	m
PIPING	n	m
C. OTHER STRUCTURES		
LINERS	n	m
DIVERSION WORKS - FLOODS	n	M
- GULLEY EROSION	n	m
- ICE & DEBRIS BLOCKAGE	m	M-s
- SEDIMENTATION	m	M
SURFACE WATER QUALITY - WITHOUT TREATMENT	s	s
- WITH TREATMENT	m	m
SEEPAGE CONTROL MEASURES	n	m

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occuring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

TABLE I.6.A-5

EXISTING AND LONG TERM STABILITY OF STANROCK TAILINGS AREA

MODE OF INSTABILITY	PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS		
SHEET EROSION	m	M
GULLEYING	M	M-s
WIND EROSION	m	m
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION	M	M-s
DIFFERENTIAL SETTLEMENT	m	m
FROST HEAVE	m	m
INFILTRATION	m - M	M
B. EMBANKMENTS		
SHEET EROSION	M	s
GULLEYING	M	s
FLOOD EROSION	m	M
WIND EROSION	M	M
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION/PRECIPITATION	m	m
FROST ACTION - SLOUGHING	N/A	N/A
- UNDERDRAIN BLOCKAGE	N/A	N/A
PHYSICAL INSTABILITY	m	M
PIPING	m	m
C. OTHER STRUCTURES		
LINERS	m	m
DIVERSION WORKS - FLOODS	m	M
- GULLEY EROSION	m	M
- ICE & DEBRIS BLOCKAGE	m	M-s
- SEDIMENTATION	m	M
SURFACE WATER QUALITY - WITHOUT TREATMENT	s	s
- WITH TREATMENT	m	m
SEEPAGE CONTROL MEASURES	N/A	N/A

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occuring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

TABLE I.6.A-6

EXISTING AND LONG-TERM STABILITY OF QUIRKE TAILINGS AREA

MODE OF INSTABILITY	PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS		
SHEET EROSION	m	M
GULLEYING	m	M-s
WIND EROSION	m	M
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION	m	M
DIFFERENTIAL SETTLEMENT	m	m
FROST HEAVE	m	m
INFILTRATION	m - M	M
B. EMBANKMENTS		
SHEET EROSION	m	M
GULLEYING	m	M
FLOOD EROSION	m	M
WIND EROSION	m	m
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION/PRECIPITATION	n	m
FROST ACTION - SLOUGHING	N/A	N/A
- UNDERDRAIN BLOCKAGE	N/A	N/A
PHYSICAL INSTABILITY	m	m
PIPING	m	m-M
C. OTHER STRUCTURES		
LINERS	n	m
DIVERSION WORKS - FLOODS	m	s
- GULLEY EROSION	m-M	s
- ICE & DEBRIS BLOCKAGE	m	M
- SEDIMENTATION	m	M
SURFACE WATER QUALITY - WITHOUT TREATMENT	s	s
- WITH TREATMENT	m	m
SEEPAGE CONTROL MEASURES	n	m

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occuring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

TABLE I.6.A-7

EXISTING AND LONG-TERM STABILITY OF STANLEIGH TAILINGS AREA

MODE OF INSTABILITY	PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS		
SHEET EROSION	m	M
GULLEYING	M	m-s
WIND EROSION	m	m
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION	m	M
DIFFERENTIAL SETTLEMENT	m	m
FROST HEAVE	m	m
INFILTRATION	m - M	M
B. EMBANKMENTS		
SHEET EROSION	m	M
GULLEYING	m	M-s
FLOOD EROSION	m	M
WIND EROSION	m	m
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION/PRECIPITATION	m	m
FROST ACTION - SLOUGHING	N/A	N/A
- UNDERDRAIN BLOCKAGE	N/A	N/A
PHYSICAL INSTABILITY	m	m
PIPING	n	m
C. OTHER STRUCTURES		
LINERS	n	m
DIVERSION WORKS - FLOODS	n	M
- GULLEY EROSION	m	M
- ICE & DEBRIS BLOCKAGE	m	M-s
- SEDIMENTATION	m	M
SURFACE WATER QUALITY - WITHOUT TREATMENT	s	s
- WITH TREATMENT	m	m
SEEPAGE CONTROL MEASURES	n	m

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occuring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

TABLE I.6.A-8

EXISTING AND LONG TERM STABILITY OF PANEL TAILINGS AREA

MODE OF INSTABILITY	PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS		
SHEET EROSION	m	M
GULLEYING	m	M-s
WIND EROSION	m	m
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION	m	M
DIFFERENTIAL SETTLEMENT	m	m
FROST HEAVE	m	m
INFILTRATION	m - M	M
B. EMBANKMENTS		
SHEET EROSION	m	M
GULLEYING	m	M-s
FLOOD EROSION	m	M
WIND EROSION	m	m
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION/PRECIPITATION	n	m
FROST ACTION - SLOUGHING	N/A	N/A
- UNDERDRAIN BLOCKAGE	N/A	N/A
PHYSICAL INSTABILITY	m	m
PIPING	n	M
C. OTHER STRUCTURES		
LINERS	n	m
DIVERSION WORKS - FLOODS	m	M
- GULLEY EROSION	m	M
- ICE & DEBRIS BLOCKAGE	M	M-s
- SEDIMENTATION	M	M
SURFACE WATER QUALITY - WITHOUT TREATMENT	s	s
- WITH TREATMENT	m	m
SEEPAGE CONTROL MEASURES	m	M

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occuring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

TABLE I.6.A-9

EXISTING AND LONG-TERM STABILITY OF SPANISH AMERICAN TAILINGS AREA

MODE OF INSTABILITY	PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS		
SHEET EROSION	m	M
GULLEYING	m	M-s
WIND EROSION	m	m
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION	m	M
DIFFERENTIAL SETTLEMENT	m	m
FROST HEAVE	m	m
INFILTRATION	m - M	M
B. EMBANKMENTS		
SHEET EROSION	N/A	N/A
GULLEYING	N/A	N/A
FLOOD EROSION	N/A	N/A
WIND EROSION	N/A	N/A
BIOLOGICAL PENETRATION	N/A	N/A
SALT MIGRATION/PRECIPITATION	N/A	N/A
FROST ACTION - SLOUGHING	N/A	N/A
- UNDERDRAIN BLOCKAGE	N/A	N/A
PHYSICAL INSTABILITY	N/A	N/A
PIPING	N/A	N/A
C. OTHER STRUCTURES		
LINERS	m	m
DIVERSION WORKS - FLOODS	N/A	N/A
- GULLEY EROSION	N/A	N/A
- ICE & DEBRIS BLOCKAGE	N/A	N/A
- SEDIMENTATION	N/A	N/A
SURFACE WATER QUALITY - WITHOUT TREATMENT	s	s
- WITH TREATMENT	m	m
SEEPAGE CONTROL MEASURES	N/A	N/A

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occuring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

TABLE I.6.A-10

EXISTING AND LONG-TERM STABILITY OF LACNOR & NORDIC TAILINGS AREAS

MODE OF INSTABILITY	PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS		
SHEET EROSION	m	M
GULLEYING	m	M-s
WIND EROSION	m	m
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION	m	M
DIFFERENTIAL SETTLEMENT	m	m
FROST HEAVE	m	m
INFILTRATION	m - M	M
B. EMBANKMENTS		
SHEET EROSION	m	M
GULLEYING	m	M-s
FLOOD EROSION	m	M
WIND EROSION	m	m
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION/PRECIPITATION	m	m
FROST ACTION - SLOUGHING	N/A	N/A
- UNDERDRAIN BLOCKAGE	N/A	N/A
PHYSICAL INSTABILITY	M	M
PIPING	n	M
C. OTHER STRUCTURES		
LINERS	s	s
DIVERSION WORKS - FLOODS	M	M-s
- GULLEY EROSION	M	M-s
- ICE & DEBRIS BLOCKAGE	M	M-s
- SEDIMENTATION	M	M-s
SURFACE WATER QUALITY - WITHOUT TREATMENT	s	s
- WITH TREATMENT	m	m
SEEPAGE CONTROL MEASURES	N/A	N/A

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occurring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

minor, moderate or severe instability refers purely to the mode of instability and does not imply an assessment of tailings or contaminant release rates. Releases are presently prevented by both secondary containment measures and by maintenance. Future release could be prevented by maintenance or in the implementation of alternative reclamation measures.

I.6.11.B STABILITY OF THE IMPOUNDMENTS, SASKATCHEWAN

The existing and anticipated stability of the various impoundments is summarized in Tables I.6.B-10 to -15.

TABLE I.6.B-10

EXISTING AND LONG-TERM STABILITY OF CLUFF LAKE TAILINGS AREA

MODE OF INSTABILITY	PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS		
SHEET EROSION	N/A	M-s
GULLEYING	N/A	M-s
WIND EROSION	N/A	M-s
BIOLOGICAL PENETRATION	N/A	UN
SALT MIGRATION	N/A	m-M
DIFFERENTIAL SETTLEMENT	N/A	M
FROST HEAVE	N/A	M
INFILTRATION	N/A	M-s
B. EMBANKMENTS		
SHEET EROSION	M	M
GULLEYING	m	M
FLOOD EROSION	n	m
WIND EROSION	n	M-s
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION/PRECIPITATION	n	M-s
FROST ACTION - SLOUGHING	UN	M
- UNDERDRAIN BLOCKAGE	UN	M-s
PHYSICAL INSTABILITY	m	m
PIPING	n	m-M
C. OTHER STRUCTURES		
LINERS	n	m
DIVERSION WORKS - FLOODS	m	M-s
- GULLEY EROSION	m	M
- ICE & DEBRIS BLOCKAGE	m	M-s
- SEDIMENTATION	m	M-s
SURFACE WATER QUALITY - WITHOUT TREATMENT	s	s
- WITH TREATMENT	m	m
SEEPAGE CONTROL MEASURES	m	m

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occuring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

TABLE I.6.B-11

EXISTING AND LONG-TERM STABILITY OF KEY LAKE TAILINGS AREA

MODE OF INSTABILITY	PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS		
SHEET EROSION	m	s
GULLEYING	m	s
WIND EROSION	m	s
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION	n	m
DIFFERENTIAL SETTLEMENT	m	m
FROST HEAVE	m	m-M
INFILTRATION	m-M	m-M
B. EMBANKMENTS		
SHEET EROSION	M	M-s
GULLEYING	M-s	M-s
FLOOD EROSION	n	m
WIND EROSION	m	m-M
BIOLOGICAL PENETRATION	UN	UN
SALT MIGRATION/PRECIPITATION	n	m
FROST ACTION - SLOUGHING	n	M
- UNDERDRAIN BLOCKAGE	n	M
PHYSICAL INSTABILITY	m	M
PIPING	n	m
C. OTHER STRUCTURES		
LINERS	n	m
DIVERSION WORKS - FLOODS	m	M
- GULLEY EROSION	m	m
- ICE & DEBRIS BLOCKAGE	m	M
- SEDIMENTATION	m	M
SURFACE WATER QUALITY - WITHOUT TREATMENT	s	s
- WITH TREATMENT	m	m
SEEPAGE CONTROL MEASURES	m	m-s

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occuring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

TABLE I.6.B-12

EXISTING AND LONG-TERM STABILITY OF RABBIT LAKE TAILINGS AREA

MODE OF INSTABILITY		PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS			
SHEET EROSION		m	m
GULLEYING		m	M
WIND EROSION		m	s
BIOLOGICAL PENETRATION		UN	UN
SALT MIGRATION		n	M
DIFFERENTIAL SETTLEMENT		m	s
FROST HEAVE		M	M-s
INFILTRATION		m - M	M-s
B. EMBANKMENTS			
SHEET EROSION		M	s
GULLEYING		m	s
FLOOD EROSION		n	m
WIND EROSION		m	m
BIOLOGICAL PENETRATION		UN	UN
SALT MIGRATION/PRECIPITATION		n	M-s
FROST ACTION	- SLOUGHING	m	s
	- UNDERDRAIN BLOCKAGE	n	M-s
PHYSICAL INSTABILITY		m	s
PIPING		m	M-s
C. OTHER STRUCTURES			
LINERS		n	n
DIVERSION WORKS	- FLOODS	m	m
	- GULLEY EROSION	m	m
	- ICE & DEBRIS BLOCKAGE	m	M
	- SEDIMENTATION	m	M
SURFACE WATER QUALITY	- WITHOUT TREATMENT	s	s
	- WITH TREATMENT	m	m
SEEPAGE CONTROL MEASURES		M	s

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occuring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

TABLE I.6.B-13

EXISTING AND LONG-TERM STABILITY OF COLLINS BAY TAILINGS AREA

MODE OF INSTABILITY		PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS			
SHEET EROSION		n	m
GULLEYING		n	M
WIND EROSION		n	M
BIOLOGICAL PENETRATION		n	UN
SALT MIGRATION		n	m
DIFFERENTIAL SETTLEMENT		m	m
FROST HEAVE		m-M	m
INFILTRATION		m-M	m-M
B. EMBANKMENTS			
SHEET EROSION		N/A	N/A
GULLEYING		N/A	N/A
FLOOD EROSION		N/A	N/A
WIND EROSION		N/A	N/A
BIOLOGICAL PENETRATION		N/A	N/A
SALT MIGRATION/PRECIPITATION		N/A	N/A
FROST ACTION	- SLOUGHING	N/A	N/A
	- UNDERDRAIN BLOCKAGE	N/A	N/A
PHYSICAL INSTABILITY		N/A	N/A
PIPING		N/A	N/A
C. OTHER STRUCTURES			
LINERS		m	m-M
DIVERSION WORKS	- FLOODS	n	n
	- GULLEY EROSION	n	n
	- ICE & DEBRIS BLOCKAGE	n	n
	- SEDIMENTATION	n	n
SURFACE WATER QUALITY	- WITHOUT TREATMENT	M	m-M
	- WITH TREATMENT	m	m
SEEPAGE CONTROL MEASURES		m	m

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occuring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

TABLE I.6.B-14

EXISTING AND LONG-TERM STABILITY OF GUNNAR TAILINGS AREA

MODE OF INSTABILITY		PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS			
SHEET EROSION		M-s	M-s
GULLEYING		M-s	M-s
WIND EROSION		s	s
BIOLOGICAL PENETRATION		s	s
SALT MIGRATION		M	M
DIFFERENTIAL SETTLEMENT		M-s	M-s
FROST HEAVE		M-s	M-s
INFILTRATION		s	s
B. EMBANKMENTS			
SHEET EROSION		N/A	N/A
GULLEYING		N/A	N/A
FLOOD EROSION		N/A	N/A
WIND EROSION		N/A	N/A
BIOLOGICAL PENETRATION		N/A	N/A
SALT MIGRATION/PRECIPITATION		N/A	N/A
FROST ACTION	- SLOUGHING	N/A	N/A
	- UNDERDRAIN BLOCKAGE	N/A	N/A
PHYSICAL INSTABILITY		N/A	N/A
PIPING		N/A	N/A
C. OTHER STRUCTURES			
LINERS		N/A	N/A
DIVERSION WORKS	- FLOODS	N/A	N/A
	- GULLEY EROSION	N/A	N/A
	- ICE & DEBRIS BLOCKAGE	N/A	N/A
	- SEDIMENTATION	N/A	N/A
SURFACE WATER QUALITY	- WITHOUT TREATMENT	N/A	N/A
	- WITH TREATMENT	N/A	N/A
SEEPAGE CONTROL MEASURES		N/A	N/A

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occuring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

TABLE I.6.B-15

EXISTING AND LONG-TERM STABILITY OF LORADO TAILINGS AREA

MODE OF INSTABILITY		PRESENT CONDITIONS	FUTURE POTENTIAL
A. COVERS			
SHEET EROSION		s	s
GULLEYING		s	s
WIND EROSION		s	s
BIOLOGICAL PENETRATION		M	s
SALT MIGRATION		s	s
DIFFERENTIAL SETTLEMENT		m	m
FROST HEAVE		m-M	M-s
INFILTRATION		s	s
B. EMBANKMENTS			
SHEET EROSION		N/A	N/A
GULLEYING		N/A	N/A
FLOOD EROSION		N/A	N/A
WIND EROSION		N/A	N/A
BIOLOGICAL PENETRATION		N/A	N/A
SALT MIGRATION/PRECIPITATION		N/A	N/A
FROST ACTION	- SLOUGHING	N/A	N/A
	- UNDERDRAIN BLOCKAGE	N/A	N/A
PHYSICAL INSTABILITY		N/A	N/A
PIPING		N/A	N/A
C. OTHER STRUCTURES			
LINERS		N/A	N/A
DIVERSION WORKS	- FLOODS	N/A	N/A
	- GULLEY EROSION	N/A	N/A
	- ICE & DEBRIS BLOCKAGE	N/A	N/A
	- SEDIMENTATION	N/A	N/A
SURFACE WATER QUALITY	- WITHOUT TREATMENT	N/A	N/A
	- WITH TREATMENT	N/A	N/A
SEEPAGE CONTROL MEASURES		N/A	N/A

NOTES:

(i) Present conditions refers to current experience for the respective mode of instability, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(ii) Future potential conditions refers to the potential of releases occuring over a 200 to a 2000 year period if no extensive abandonment measures are implemented, classed as;

n - none
m - minor
M - moderate
s - severe
N/A - not applicable
UN - unknown

(iii) Evaluations of present or future instability do not imply potential for tailings releases which can be prevented by maintenance, secondary containment or implemention of alternative reclamation measures.

I.7.0 REFERENCES

Amok Ltd. 1983. Water Quality Reports for August, 1983. Prepared for Atomic Energy Control Board.

Amok Ltd. 1985. Cluff Lake Uranium Mine Annual Report. Prepared for Saskatchewan Environment, Mines and Pollution Branch.

Blowes, D. 1983. The Influence of the Capillary Fringe on the Quantity and Quality of Runoff in an Active Uranium Mill Tailings Impoundment. Unpublished M.Sc. Thesis from the University of Waterloo.

Boyd, J.M., Carter, T.G., Knapp, R.A., and Culver, K.B. 1982. Hydrogeological Investigations and Evaluation of the Stanleigh Mine Tailings Impoundment Site. International Symposium on Management of Wastes from Uranium Mining and Milling, Albuquerque.

Brooks, B.W. 1981. Revegetation of the Waite Amulet Tailings Discharge Area. Proceedings of the 13th Annual Meeting of Canadian Mineral Processors, Ottawa, pages 341-363. Canadian Institute of Mining and Metallurgy, Montreal, P.Q.

Bush, K.J., and Markos, G. 1981. Evidence for the Instability of Silicate Minerals in Acid Leach Uranium Mill Tailings. 4th Symposium on Uranium Mill Tailings Management, Fort Collins, Colorado.

Canadian Climate Program. 1982. Canadian Climate Normal, 1951-1980, Temperature and Precipitation. Environment Canada.

Chakravatti, J.L. 1986. Personal Communication. Denison Mines Limited.

Cherry, J.A., Blackport, R.A., Dubrovsky, N., Gillham, R.W., Lim, T.P., Murray, D., Reardon, E.J. and Smyth, D.J.A. 1980. Subsurface Hydrology and Geochemical Evolution of Inactive Pyritic Tailings in the Elliot Lake Uranium District, Canada. 3rd Symposium on Uranium Mill Tailings Management, Fort Collins, Colorado.

Cherry, J.A., Shepherd, T.A. and Morin, K.A. 1982. Chemical Composition and Geochemical Behavior of Contaminated Groundwater at Uranium Tailings Impoundments, SME-AIME Annual Meeting, Dallas, Texas

Clifton Associates Ltd. 1985. Preliminary Draft Report Earth Barriers Study. Prepared for Department of Energy, Mines and Resources, Canadian Centre for Mineral and Energy Technology, National Uranium Tailings Program.

Cluff Lake Board of Inquiry. 1978. Final Report.

Cluff Mining. 1982. Cluff Lake Development, Phase II, Environmental Impact Assessment.

Coke, W.B. and DiLabio, R.N.W. 1979. Initial Geochemical Results and Exploration Significance of Two Uraniferous Peat Bogs, Kasmere Lake, Manitoba. Current Research, Part B, Geological Survey of Canada.

Culver, K.B., Chakravatti, J.L., Gorber, D.M., Knapp, R.A., and Davis, J.B. 1982. Close-out Concepts for the Elliot Lake Uranium Mining Operations. International Symposium on Management of Wastes from Uranium Mining and Milling, Albuquerque, New Mexico, pp. 157-168.

Dave, N.K. and Lim, T.P. 1982. Hydrogeochemical Evolution of an Inactive Pyritic Uranium Tailings Basin and Retardation of Contaminant Migration in a Surrounding Aquifer. Int. Symp. on Mngt. of Wastes from Uranium Mining and Milling, Albuquerque, New Mexico, U.S.A., 10-14 May.

Dave, N.K. and Lim, T.P. 1986. Personal Communication. Energy, Mines and Resources.

Dave, N.K., Lim, T.P., and Cloutier, N.R. 1985. Ra-226 Concentrations in Blueberries Vaccinium Angustifolium Ait. Near an Inactive Uranium Tailings Site in Elliot Lake, Ontario, Canada. Environmental Pollution (Series B) 10, pp. 301-314.

Dave, N.K., Lim, T.P. and Vivyurka, A.J. 1981. Chemical and Radioisotope Distribution Profiles in an Abandoned Uranium Tailings Pile. 4th Symposium on Uranium Mill Tailings Management, Fort Collins, Colorado. pp. 343-366.

Dave, N.K., Lim, T.P., Vivyurka,A.J., Dubrovsky, N., Morin, K.A., Smyth, D.J.A., Gillham, R.W. and Cherry, J.A. 1982. Hydrogeochemical Evolution of an Inactive Pyritic Uranium Tailings Basin and Retardation of Contaminant Migration in a Surrounding Aquifer. International Symposium on Management of Wastes from Uranium Mining and Milling, Albuquerque.

Deutsch, W.J., Seerne, R.J., Bell, N.E. and Martin, W.J. 1983. Aquifer Restoration at In-Situ Leach Uranium Mines: Evidence for Natural Restoration Processes. Report PNL-4604/NUREG/CR-3136, Pacific Northwest Laboratory, U.S. Nuclear Regulatory Commission, Washington, D.C.

DSMA Atcon Ltd. 1985. A Study to Measure and Evaluate the Effect that Vegetation has on the Emanation Rate of Radon from a Uranium Tailings Pile. Prepared for Department of Energy, Mines and Resources, Canadian Centre for Mineral and Energy Technology, National Uranium Tailings Program. Report No. 1357/1335.

Dubrovsky, N.M., Cherry, J.A., Reardon, E.J. and Vivyurka, A.J. 1985. Geochemical Evolution of Inactive Pyritic Tailings in the Elliot Lake Uranium District. Canadian Geotechnical Journal. Vol. 22, pp 110-128.

Dunn, R.W., L.A. Melis, and A.J. Vivyurka. 1977. The Pollution Control Program of Rio Algom Mines Limited in the Elliot Lake Program, Part I. Tailings Revegetation; Part 2. Seepage Treatment and Control. Rio Algom Mines Ltd.

Eldorado Resources Limited. 1984. Eldor Mines Annual Report - As submitted to the A.E.C.B, March 7.

Feenstra, S., Blair, R.D., Cherry, J.A., Chakravatti, J.L. and LaRocque, E. 1981. Hydrogeochemical Investigation of Two Inactive Tailings Areas in the Elliot Lake Uranium District, Ontario, Canada. 4th Symposium on Uranium Mill Tailings Management, Fort Collins, Colorado. pp 367-388.

Gardiner, R.T. 1977. Tailings Revegetation Experience at Cominco Ltd., Metal Mines in B.C. and the N.W.T. Proceedings 1st Annual Meeting British Columbia Mine Reclamation Symposium, Vernon, B.C., pages 35-54. B.C. Ministry of Mines and Petroleum Resources, Victoria, B.C.

Geocon (1975) Ltd. 1973. Phase III, Geotechnical Design and Specifications - Gulf Minerals Canada Limited - Uranium Development Project Site 8 Tailings Area - Report to Fluor Utah Ltd., Dec. 7.

Geocon (1975) Ltd. 1978. Progress Report No. 2 - Additional Geotechnical Investigation Laboratory Testing - Peat Samples - Tailings Disposal Area Prepared for Amok Ltd., October 24.

Geocon (1975) Ltd. 1980a. 1980 Construction - Tailings Area Dams - Rabbit Lake Uranium Mine - Report to Gulf Minerals Canada Limited, Dec.18.

Geocon (1975) Ltd. 1980b. Appendix I - Soils Exploration. Environmental Impact Statement for Collins Bay B-Zone Development, Rabbit Lake Operation

Geocon (1975) Ltd. 1980c. Soil/Bentonite Cutoff Wall Inspection - Tailings Area Report to Amok Ltd., January 25.

Geocon (1975) Ltd. 1980d. Phase I Dam Design - Tailings Management Facility Report to Amok Ltd., January 31.

Geocon Inc. 1981. 1981 Construction - Tailings Area Dams - Rabbit Lake Uranium Mine - Report to Gulf Minerals Canada Limited, Dec.15.

Geocon Inc. 1982a. Tailings Seepage Study Rabbit Lake Uranium Mine. Report to Gulf Minerals Canada Limited.

Geocon Inc. 1982b. 1982 Construction - Tailings Area Dams - Rabbit Lake Uranium Mine - Report to Eldor Mines

Geocon Inc. 1982c. Design and Stability Analyses - Proposed Dam Extension to El. 1475 - Rabbit Lake Uranium Mine - Tailing Area, June.

Geocon Inc. 1984a. 1983 Construction - Tailing Area Dams - Rabbit Lake Mine Report to Eldor Mines, February 28.

Geocon Inc. 1984b. Disposal of Tailing in Rabbit Lake Pit Collins Bay B-Zone Development Preliminary Design Report to Eldor Mines, April.

Geotechnical Group. 1985a. Year End Report, Amok Ltd./Cluff Lake Mining Research Program. January 15.

Geotechnical Group. 1985b. Year End Report, Amok Ltd./Cluff Lake Mining Research Program. April 24.

Golder Associates. 1983. Laboratory Testing Program to Determine Physical Properties of the Phase I Extension Tailings Report to Cluff Mining

Golder Associates (Eastern Canada) Ltd. 1981a. Geotechnical Investigation and Design Recommendations Dam J. Reference No. 801-1089-2, January.

Golder Associates (Eastern Canada) Ltd. 1981b. Geotechnical Investigation and Design - Dams 9 & 10 - Tailings Management Area - Stanleigh Project. Reference No. 791-1347-6, February.

Golder Associates (Eastern Canada) Ltd. 1981c. Geotechnical Investigation and Design Recommendations Dam I. Reference No. 801-1089-4, February.

Golder Associates (Eastern Canada) Ltd. 1981d. Geotechnical Investigation and Design Recommendations Dam G1 Quirke Tailings Basin Expansion. Reference No. 801-1089-5, February.

Golder Associates (Eastern Canada) Ltd. 1981e. Geotechnical Investigation & Design. Dam A, Tailings Management Area Stanleigh Project. Reference No. 791-1347-7, March.

Golder Associates (Eastern Canada) Ltd. 1981f. Geotechnical Investigation & Design. Dam B, Tailings Management Area Stanleigh Project. Reference No.791-1347-8, March.

Golder Associates (Eastern Canada) Ltd. 1981g. Hydrogeochemical Investigation Williams Lake Tailings Management Area. Reference No. 801-1019, March. (Draft Report).

Golder Associates (Eastern Canada) Ltd. 1981h. Hydrogeochemical Investigation Stanrock Tailings Management Area. Reference No. 801-1019-1, April. (Draft Report).

Golder Associates (Eastern Canada) Ltd. 1981i. Borrow Materials Investigation. Quirke Mines Tailings Basin Expansion. Reference No. 801-1051, May.

Golder Associates (Eastern Canada) Ltd. 1981j. Stability of the East Dyke Quirke Mine Tailings Management Area. Reference 801-1089-12, June.

Golder Associates (Eastern Canada) Ltd. 1981k. Geotechnical Investigation and Design Recommendations Dam G2. Reference No. 801-1089-6, September.

Golder Associates (Eastern Canada) Ltd. 1981l. Geotechnical Investigation and Design Recommendations Dam K1. Reference No. 801-1089-7, September.

Golder Associates (Eastern Canada) Ltd. 1981m. Geotechnical Investigation and Design Recommendations Dam K2. Reference No. 801-1089-8, September.

Golder Associates (Eastern Canada) Ltd. 1981n. Geotechnical Investigation and Design Recommendations Dam L. Reference No. 801-1089-10, October.

Golder Associates (Eastern Canada) Ltd. 1981o. Foundation Bedrock Grouting Design Brief for Dams G2, K1, K2 and L, Quirke Tailings Basin Expansion. Reference No. 801-1089-13, November.

Golder Associates (Eastern Canada) Ltd. 1982a. Stability of Internal Dykes, Quirke Mine Tailings Management Area. Reference No. 801-1240, March.

Golder Associates (Eastern Canada) Ltd. 1982b. As-Built Report Dams A & B - Stage I, Crotch Lake Tailings Management Scheme - Stanleigh Project. Reference No. 811-1326, November.

Golder Associates (Eastern Canada) Ltd. 1984. Evaluation of Flexible Membrane Liners as Long-term Barriers for Uranium Mill Tailings. Phase I. Prepared for Department of Energy, Mines and Resources, Canadian Centre for Mineral and Energy Technology, National Uranium Tailings Program. July.

Golder Associates (Eastern Canada) Ltd. and Senes Consultants. 1985. Uranium Tailings Sampling Manual. Prepared for Department of Energy, Mines and Resources, Canadian Centre for Mineral and Energy Technology, National Uranium Tailings Program. NUTP-1E.

Gray, Donald M. 1970. Handbook on the Principles of Hydrology. Water Information Center Inc.

Ground Engineering Ltd. 1978. Volume II: Appendices A to H - Waste Management System Tailings Pond - Site C Prepared for Uranerz Exploration & Mining Limited

Gulf Minerals Canada Limited. 1980a. Collins Bay B-Zone Development - Rabbit Lake Operation Environmental Impact Statement - Volume 1 - Summary Statement June

Gulf Minerals Canada Limited. 1980b. Collins Bay B-Zone Development - Rabbit Lake Operation Environmental Impact Statement - Volume 2 - Appendices A to E, June.

Gulf Minerals Canada Limited. 1980c. Collins Bay B-Zone Development - Rabbit Lake Operation Environmental Impact Statement - Volume 3 - Appendices F and G. June.

Gulf Minerals Canada Limited. 1981a. Collins Bay B-Zone Development - Rabbit Lake Operation Environmental Impact Statement - First Addendum, March

Gulf Minerals Canada Limited. 1981b. Collins Bay B-Zone Development - Rabbit Lake Operation Environmental Impact Statement - Second Addendum, June

Gulf Minerals Canada Limited. 1981c. Collins Bay B-Zone Development - Rabbit Lake Operation Environmental Impact Statement - Third Addendum, November

Hanney, K.E., Jurgens, E.I., Comrie, D.C. and Fletcher, R.H. 1980. Reclamation Concepts and Practice for Uranium Tailings Impoundments. First International Conference on Uranium Waste Disposal, Vancouver. pp 521-554.

Haughton, D.R. and Smith, J.W.J. 1974. Collection, Analysis and Computer-Based Documentation of Geochemical Samples in the Precambrian of Sask. Report 14 Geology Division, Sask. Research Council

H.Q. Golder & Associates Ltd. 1972. Geotechnical Aspects of Design, Long Lake Tailings Dam. Reference No.71065-1, February.

H.Q. Golder & Associates Ltd, 1974. Geotechnical Investigation Stanrock Uranium Mines Limited Tailings Disposal Area. Reference No. 73023-1, January.

H.Q. Golder & Associates Ltd. 1977. Geotechnical Investigation Strike Lake Tailings Impoundment. Reference No. 771031, November.

H.Q. Golder & Associates Ltd. 1978a. Review of Stability and Seepage Conditions Rio Algom Tailings Retention Areas. Reference No. 771032, January.

H.Q. Golder & Associates Ltd. 1978b. Bedrock Reconnaissance Strike Lake Tailings Impoundment. Reference No. 771031-R, February.

H.Q. Golder & Associates Ltd. 1978c. Geotechnical Investigation Existing Quirke Mine Tailings Management Area, Volume I. Reference No. 771051, March.

H.Q. Golder & Associates Ltd. 1978d. Geotechnical Investigation and Study, Close-out of Stanrock Tailings Storage Area. Reference No. 771179, April.

H.Q. Golder & Associates Ltd. 1978e. Stability and Seepage Aspects of Existing Dams and Dykes Minesite and Stanrock Tailings Management Areas. Reference No. 761340-1, June.

H.Q. Golder & Associates Ltd. 1978f. Geotechnical Investigation Existing Quirke Mine Tailings Management Area, Volume II. Reference No. 771051, June. (Draft Report)

H.Q. Golder & Associates Ltd. 1978g. Geotechnical Aspects of Close-out Williams Lake Tailings Management Area. December.

H.Q. Golder & Associates Ltd. 1979. Supplementary Data Strike Lake Tailings Impoundment. Reference No. 771031-1, April.

H.Q. Golder & Associates Ltd. 1980a. Revised Design, Dam No. 17, Volumes I and II, Denison Mines Tailings Management Area. Reference No.781235, April.

H.Q. Golder & Associates Ltd. 1980b. Philosophy of Groundwater Flow Modelling for Tailings Basins. Reference No.801-1087, April.

H.Q. Golder & Associates Ltd. 1980c. Denison Mines Tailings Management Areas. Reference No. 781231, July.

H.Q. Golder & Associates Ltd. 1980d. Hydrogeological Assessment of the Tailings Impoundment Basin, Part A Stanleigh Mine Tailings Impoundment, Volume 3. June.

H.Q. Golder & Associates Ltd. 1980e. Geotechnical Investigations and Design Recommendations Lake C Diversion Scheme (Dam H and Diversion Channel) Quirke Tailings Basin Expansion. Reference No. 801-1089-1, August.

James F. MacLaren Limited. 1977a. Site Selection and Recommended Deposition Scheme, Panel Mine Tailings Impoundment, Volume 1. November.

James F. MacLaren Limited. 1977b. Environmental Assessment of the Proposed Elliot Lake Uranium Mines Expansion, Volume 1, Background Information. March.

James F. MacLaren Limited. 1978a. Environmental Assessment of the Proposed Elliot Lake Uranium Mines Expansion, Volume 2, Background Information Update. February.

James F. MacLaren Limited. 1978b. Environmental Assessment of the Proposed Elliot Lake Uranium Mines Expansion, Volume 4, Environmental Assessment. April.

James F. MacLaren Limited. 1978c. Environmental Considerations for the Engineering Study on the Stanleigh Uranium Mine. Internal Report, June.

James F. MacLaren Limited. 1979a. Environmental Studies at the Lacnor-Nordic Tailings Area. Report, March.

James F. MacLaren Limited. 1979b. Williams Lake Tailings Management Area, Hydrologic Aspects. Reference No. 11583-0, Report, April.

James F. MacLaren Limited, 1980. Stanrock Tailings Management Area - Hydrologic Aspects. Reference No. 11584-0, Internal Report, March.

James F. MacLaren Ltd. and H.Q. Golder & Associates Ltd. 1978. Design Brief Construction of 1978 Facilities, Panel Mine Tailings Impoundment, Volume III. February.

James F. MacLaren Ltd. and H.Q. Golder & Associates Ltd. 1979a. Tailings Deposition Scheme and Details of Tailings Effluent Treatment System, Panel Mine Tailings Impoundment, Volume VI. May.

James F. MacLaren Ltd. and H.Q. Golder & Associates Ltd. 1979b. Site Selection and Recommended Deposition Scheme Stanleigh Mine Tailings Impoundment, Volume I. June.

James F. MacLaren Ltd. and H.Q. Golders & Associates Ltd. 1980. Quirke Mine Tailings Impoundment, Volume II, Site Selection Report. February.

Jewett, J. 1986. Personal Communication. Ministry of Natural Resources, Lands Division.

Johnson, K. 1985. Geochemistry of Uranium Wastes. Engineering of Waste Management Systems Seminar, University of Saskatchewan, College of Engineering, Saskatoon.

Kalin, M. 1981. A Preliminary Assessment of the Environmental Conditions of Two Abandoned Uranium Mill Tailings Sites in Saskatchewan. Submitted to Saskatchewan Environment and Environment Canada. Surveillance Report EPS-5-WNR-81-1.

Kalin, M. 1983. Long-term Ecological Behaviour of Abandoned Uranium Mill Tailings. 1. Synoptic Identification of Invading Biota. Technology Development Report EPS 4-ES-83-1, Environmental Protection Service, Environment Canada, Ottawa.

Key Lake Mining Corporation. 1982. Performance of Tailings Deposited under Winter Conditions, Internal Report.

Key Lake Mining Corporation. 1982. Final Safety Report. Submitted to Atomic Energy Control Board of Canada in Support of Application by Key Lake Mining Corp. for a Mining Facility Operating License

Key Lake Mining Corporation. 1984. Environmental Year-End Monitoring Report - 1983 Prepared for Sask. Environment, Mines Pollution Control Branch.

Key Lake Mining Corporation. 1985a. Environmental Year End Monitoring Report - 1984. Prepared for Sask. Environment, Mines Pollution Control Branch.

Key Lake Mining Corporation. 1985b. Annual Hydrogeological Report - 1984. Prepared for Sask. Environment, Mines Pollution Control Branch.

Knight and Piesold Ltd. 1978. Review of Alternative Sites and Selection of Prime Location for Mill and Waste Disposal Sites (Semi-Detailed Study). Prepared for Uranerz Exploration & Mining Limited, May.

Knight and Piesold Ltd. 1981a. Tailings Storage Facility - Report on Detailed Design - Site C' - Volume I Prepared for Key Lake Mining Corporation

Knight and Piesold Ltd. 1981b. Tailings Storage Facility - Report on Detailed Design - Site C' - Volume II - Appendices Prepared for Key Lake Mining Corporation

Knight and Piesold Ltd. 1982a. Tailings Storage Facility - Report on Underseal Test Area Prepared for Key Lake Mining Corporation

Knight and Piesold Ltd. 1982b. Ore and Cobble Ore Stockpile Facility and Special Waste Stockpile Facility - Construction Report Prepared for Key Lake Mining Corporation.

Knight and Piesold Ltd. 1982c. Waste Management Facilities - Site Inspection Manual - Volume 1 Prepared for Key Lake Mining Corporation.

Knight and Piesold Ltd. 1984a. Tailings Storage Facility - Construction Report - Volume I - Main Report Prepared for Key Lake Mining Corporation.

Knight and Piesold Ltd. 1984b. Tailings Storage Facility - Construction Report Volume II - As Built Drawings Prepared for Key Lake Mining Corporation.

Knight and Piesold Ltd. 1984c. Tailings Storage Facility - Construction Report - Volume II - As Built Drawings Prepared for Key Lake Mining Corporation.

Knight and Piesold Ltd. 1985a. Tailings Storage Facility - Annual Inspection Report - 1984 Prepared for Key Lake Mining Corporation

Knight and Piesold Ltd. 1985b. Monitoring of Layered Uranium Tailings - Phase I DSS-NUTP Report #26SQ.23241-4-1679

Laliberte, R. 1986. Personal Communication. Denison Mines Limited.

LaRocque, E. 1982. Expansion of Uranium Milling at Denison Mines Limited. The 14th Canadian Mineral Processors Operators Conference.

LaRocque, E. and Pakkala, E. 1978. Current Leaching and Product Recovery Practice at Denison Mines Limited. The 17th Annual Conference of Metallurgists.

LaRocque, E. and Webber, R. 1978. Waste Management at Denison Mines. Denison Mines Limited.

Levins, D.M. 1980. Environmental Impact of Uranium Mining and Milling in Australia. CIM Bulletin, October 1980

Longmire, P. and Brookins, D. 1982. Trace Metal, Major Element, and Radionuclide Migration in Groundwater from an Acid Leaching Uranium Tailings in the Grants Mineral Belt, New Mexico. 5th Symposium on Uranium Mill Tailings Management, Fort Collins, Colorado, pp. 315-333.

Longmire, P., Hicks, R.T. and Brookins, D.G., 1981. Aqueous Geochem. Interactions Between Groundwater & Uranium Minestope Backfilling - Grants Mineral Belt, New Mexico Application of Eh-pH Diagrams. 4th Symposium on Uranium Mill Tailings Management, Fort Collins, Colorado

MacLaren Engineers, Planners & Scientists Inc. 1980. Design Brief on Hydrologic Aspects of Stanrock Tailings Area. Reference No. 11584-0, Report, September.

MacLaren Engineers, Planners & Scientists Inc. 1981. Dam B - Concrete Spillway, Submission to Regulatory Agencies. Reference No. 11505-2, Report, March.

MacLaren Engineers, Planners & Scientists Inc. 1981. Hydrologic Investigation of the Long Lake Tailings Management Area. Reference 11940-0, Report, April.

MacLaren Engineers, Planners & Scientists Inc. 1984. Feasibility Study of Decommissioning Alternatives for the Rabbit Lake Tailings Area Report to Eldorado Mines, February.

MacLaren Engineers, Planners & Scientists Inc. and Golders Associates (Eastern Canada) Ltd. 1980. Quirke Mine Tailings Impoundment, Volume III, Design Brief. December.

MacLaren Engineers, Planners & Scientists Inc. and Golder Associates (Eastern Canada) Ltd. 1981a. Design Brief, Stanleigh Mine Tailings Impoundment, Volume 5. February.

MacLaren Engineers, Planners and Scientists Inc. and Golder Associates (Eastern Canada) Ltd. 1981b. Quirke Mine Tailings Impoundment, Volume IV, Hydrogeological Assessment of the Tailings Impoundment Basin. February.

MacLaren Plansearch. 1983. Quirke Mine Tailings Management. 1983-1992.

McInnis, P. 1985. Literature Review for the National Uranium Tailings Program (NUTP) - Long-term Effects of Natural Events on Uranium Tailings Impoundments. Prepared for Department of Energy, Mines and Resources, Canadian Centre for Mineral and Energy Technology, National Uranium Tailings Program. NUTP 85-3(TR).

Maltby, J.W. 1986. Personal Communication. Rio Algom Limited.

Marshall, I.B. 1982. Mining, Land Use and the Environment, I: A Canadian Overview. Lands Directorate, Environment Canada.

Masiatka, D.W., Shepherd, T.A. and Nelson, L. 1981. Clay Liner Permeability in Low pH Environments. 4th Symposium on Uranium Mill Tailings Management, Fort Collins, Colorado

Matyas, E.L., Welch, D.E. and Reades, D.W. 1984. Geotechnical Parameters and Behaviour of Uranium Tailings. Canadian Geotechnical Journal. Vol. 21, pp 489-504.

Melis Consulting Engineers Ltd. 1985. Report submitted to Clifton Associates Ltd. for the Natural Materials as Long Term Barriers for Uranium Mine Tailings - Phase I report. pp 1-1 to 5-2.

Milligan, V., Seychuk, J.L. and Turton, R.R. (1977) Geotechnical Aspects of Disposal and Containment of Low-Level Radioactive Wastes. Proc. 24th Ontario Industrial Waste Conference, Toronto.

Mine Waste Reclamation Ltd., 1980a. Survey of Plant Growth on Nordic, Pronto and Lacnor Tailings Disposal Areas in May 1980, with Addendum. Report No. 1 to Rio Algom Mines Ltd.

Mine Waste Reclamation Ltd., 1980b. Results and Interpretation of Soil Test Analysis on Tailings Samples from Nordic, Lacnor and Pronto Tailings Disposal Areas. Report No. 2 to Rio Algom Mines Ltd.

Mine Waste Reclamation Ltd., 1980c. Review of Literature on the Applicability of Plant Tissue Analysis for Determining Nutrient Status of Tailings Vegetation and Design of Annual Fertilizer Programs. Report No. 3 to Rio Algom Ltd.

Mine Waste Reclamation Ltd., 1980d. Supplementary Reports on Results and Interpretation of Soil Test Analysis and Vegetation Composition on Tailings from Nordic, Pronto and Lacnor Tailings Disposal Areas. Report No. 4 to Rio Algom Ltd.

Mine Waste Reclamation Ltd., 1981. Evaluation of plant growth potential on uranium and copper tailings, Rio Algom Ltd., Elliot Lake, Ontario. Unpublished report prepared for Rio Algom Ltd. by Mine Waste Reclamation.

Moffett, D. 1981. Ultimate Disposal of Uranium Tailings Part 2: The Pyrite Free Tailings and Flooded Pit Experiment. Rio Algom Ltd., Report R80-08.

Morin, K.A., Cherry, J.A., Lim, T.P. and Vivyurka, A.J. 1982. Contaminant Migration in a Sand Aquifer near an Inactive Uranium Tailings Impoundment, Elliot Lake, Ontario. Canadian Geotechnical Journal, Vol. 19, pp 49-62.

Morin, K.A. 1985. 1984 Geochemical Study of the Acidic Contaminant Plume Near the Nordic Main Uranium - Tailings Impoundment, Elliot Lake National Uranium Tailings Program, DSS File 26sq.23241-4-1689.

Morrell, R. 1986. Personal Communication. Denison Mines Limited.

Morwijk Enterprises. 1985. 1984 Geochemical Study of the Acidic Contaminant Plume near the Nordic Main Uranium - Tailings Impoundment, Elliot Lake, Ontario. Prepared for Department of Energy, Mines and Resources, Canadian Centre for Mineral and Energy Technology, National Uranium Tailings Program. April.

Murray, D.R. 1977. The Influence of Uranium Mine Tailings on Tree Growth at Elliot Lake, Ontario. Proceedings 2nd Annual General Meeting Canadian Land Reclamation Association, Edmonton, Alberta. Canadian Land Reclamation Association, Guelph, Ontario.

Murray, D.R. and Moffett, D. 1977. Vegetating the Elliot Lake Uranium Mine Tailings. Journal of Soil and Water Conservation, July-August, 29-30.

Murray, D., Webber, B., and LaRocque, E. 1977. Reclamation of Lower Williams Lake Tailings Area of Denison Mines Limited. Energy, Mines and Resources Canada, Minerals Research Program.

Ontario Geological Survey. 1984. Aggregate Resources Inventory of the Town of Elliot Lake, Algoma District. Ontario Geological Survey, Aggregate Resources Inventory Paper 91, 36 p.

Ontario Water Resources Commission. 1969. An Industrial Wastes Survey of Stanrock Uranium Mines Limited, Elliot Lake, Ontario.

Opitz, B.E., Sherwood, D.R., Dodson, M.E. and Serne, R.J. 1985. Tailings Neutralization and Other Alternatives for Immobilizing Toxic Materials in Tailings. Report PNL-5467/NUREG/CR-4259, Pacific Northwest Laboratory, U.S. Nuclear Regulatory Commission, Washington, D.C.

Peterson, S.R., Erikson, R.L., and Gee, G.W. 1982. The Long Term Stability of Earthern Materials in Contact with Acidic Tailings Solutions. Report PNL-4463/NUREG/CR-2946 Pacific Northwest Laboratory, U.S. Nuclear Regulatory Commission, Washington, D.C.

Pullen, P.F. and Davis, J.B. 1981. Description of the Panel Lake Tailings Area Rio Algom Ltd., Elliot Lake, Ontario, Canada. 4th Symposium Uranium Mill Tailings Management, Fort Collins, Colorado. pp 29-44.

Radforth, N.W. and Brawner, C.O. (editors). 1982. Muskeg and the Northern Environment in Canada. University of Toronto Press, Toronto.

Rahn, P.N. and Mabe, D.L. 1978. Seepage from Uranium Tailing Ponds and Its Impact on Ground- Water. Seminar on Mngt, Stabilization and Environmental Impact of Uranium Mill Tailings, Albuquerque, New Mexico.

Reades, D.W., Davis, J.B., Goldby, H.M. and Stanlick,R.R. 1981. Remedial Works at Dam No. 1 Elliot Lake, Ontario. 4th Symposium on Uranium Mill Tailings Management, Fort Collins, Colorado. pp 507-518.

Reades, D.W., Mangan, D.P.A., Balins, J.K. and Goldby, H.M. 1982. Design and Construction of Zoned Earthfill Dams in Elliot Lake, Ontario. 35th Canadian Geotechnical Conference. pp 383-403.

Redmann, R.E. and Frankling, F.T. 1982. Revegetation of Abandoned Uranium Mill Tailings Near Uranium City, Saskatchewan Prepared for Sask. Environment and the University of Sask.

Richards, J.H. and J.I. Fung, 1969. Atlas of Saskatchewan. University of Saskatchewan, Saskatoon, Saskatchewan.

Rio Algom Ltd. The Pollution Control Program of Rio Algom Mines Ltd. in the Elliot Lake Region.

Robertson, James A. 1981. The Uranium Deposits of Ontario - Their Distribution and Classification. Ontario Geological Survey Miscellaneous Paper 86, 37 p.

Rogers, B.T., King, R.C.F., and Welch, D.E. 1982. Foundation Grouting Beneath Uranium Tailings Dams in Elliot Lake, Ontario. 35th Canadian Geotechnical Conference. pp 145-165.

Rowe, J.S. 1971. Forest Regions of Canada. Department of Fisheries and the Environment. Publication No. 1300, Ottawa.

Ruggles, R.G., Robinson, D.J. and Zaidi, A. 1978. A Study of Water Pollution in the Vicinity of Two Abandoned Uranium Mills in Northern Saskatchewan, 1978. Report EPS-WNR-5-81-2. Environmental Protection Service, Environment Canada, Ottawa.

Saskatchewan Research Council. 1982. Cluff Lake Development Phase II - Environmental Impact Assessment - Prepared for Cluff Mining, November

Sauer, E.K. and Clifton, A.W. 1985. Influence of Geology on Waste Management Practices. Waste Management Seminar, University of Saskatchewan, College of Engineering, Saskatoon, Saskatchewan.

Schreiner, B.T. 1984. Quaternary Geology of the Precambrian Shield, Sask. Report 221, Saskatchewan Geology Survey, Saskatchewan Department of Energy & Mines.

Shepherd, T.A. and Brown, S.E. no date. A Generic Model of Contaminant Migration from Uranium Tailings Impoundments.

Shilts, W.W. 1980. Geochemical profile of till from Longlac, Ontario to Somerset Island. CIM Bulletin, October, 1980.

Skinner, R.G. 1973. Glacial Tills from the Moose River Area. GSC Bulletin 225.

Smith, A.C.S., Dehrmann, A.A. and Pullen, R. 1984. The Effects of Cyanide-Bearing Gold Tailings on Water Quality of the Witwatersrand, South Africa. Proc. Conf. on Cyanide and the Environment, Vol. 1, Tucson, Arizona.

Smith, A.C.S., Caldwell, J.A. and Moore, D. 1985. Prediction of Groundwater Impact of Tailings Disposal: Cannon Mine Project. Proc. 2nd Can/Am. Conf. on Hazardous Wastes, Banff, Alberta.

Snodgrass, W.J., Lush, D.L. and Capobianco, J. 1982. Implications of Alternate Geochemical Controls on the Temporal Behaviour of Elliot Lake Tailings. Proc. Int. Conf. on Management of Waste from Uranium Mining and Milling, IEAE, Albuquerque, New Mexico, pp 285-308.

Stanlick, R. 1986. Personal Communication. Denison Mines Limited.

Statistics Canada. 1986. Personal Communication.

Stearns-Roger Incorporated. 1976a. Environmental Assessment and Safety Report Prepared for Amok Ltd., October.

Stearns-Roger Incorporated. 1976b. Appendix to Environmental Assessment and Safety Report Prepared for Amok Ltd., October.

Stevenson, D.R. 1978. Hydrogeological Evaluation of Mill and Tailings Pond Sites Report to Key Lake Mining Corporation.

Swanson, S. and A. Abouguendia. 1981. The Problem of Abandoned Uranium Tailings in Northern Saskatchewan: An Overview. SRC Publication No. C-805-48-C-81, Saskatchewan Research Council.

Taylor, M.J. and Antommaria, P.E. 1978. Immobilization of Radionuclides at Uranium Tailings Disposal Sites. 1st Symposium on Uranium Mill Tailings Management, Fort Collins, Colorado.

Thornthwaite, C.W. and Mather, J.R., 1957. Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance. Publications in Climatology X: No. 3. Drexel Institute of Technology, Centerton, New Jersey.

United States Department of Agriculture. 1972. National Engineering Handbook Section 4. USDA Soil Conservation Service, August, 1972.

Viessman, W. Jr., Knapp, J.W., Lewis, G.L., Herbaugh, T.E. 1977. Introduction to Hydrology. Second Edition, 1977. 704 p.

Vivyurka, A.J. 1986. Personal Communication. Rio Algom Limited.

W.A. Meneley Consultants Ltd. no date. Volume 3: Development of "D" Ore Body. Application for the Approval for Const. of Tailings Management Facilities and Development of the "D" Ore Body for the Amok Ltd. Uranium Project.

W.A. Meneley Consultants Ltd. no date. Application for Approval for Construction of the Tailings Management Facilities and Development of the "D" Ore Body Volume 1: Tailings Management
Facility - Prepared for Amok Ltd

W.A. Meneley Consultants Ltd. 1979. Design of Impervious Cutoff Beneath the Snake Lake Tailings Dam, July.

W.A. Meneley Consultants Ltd. 1980. Soil/Bentonite Cutoff Wall for the Phase 1 Snake Lake Tailings Dam - Prepared for Amok Ltd., February 1.

W.A. Meneley Consultants Ltd. 1982. Performance of the Phase 1 Tailings Management System Prepared for Cluff Mining, December 6.

W.A. Meneley Consultants Ltd. 1985. Cluff Lake Uranium Mine Annual Report - 1984 Prepared for Amok Ltd./Cluff Mining, March.

Watkin, E.M. and Winch, J.E. 1973. Composted Organic Wastes, Sewage Sludges and Rock Phosphate for the Amelioration of Acid Uranium Tailings. Proceedings International Conference on Land for Waste Management, Ottawa, October 1973, pages 48-56. National Research Council of Canada, Ottawa.

White, A.F., Delany, J.M., Narasimhan, T.N. and Smith, A. 1984. Groundwater Contamination from an Inactive Uranium Mill Tailings Pile 1. Application of a Chemical Mixing Model. Water Resources Research, Vol. 20.

Whiting, J., E. Christiansen, H. Heuser, J.S. Kermeen, H. Maathuis, and P. Machibroda. 1982. Summary Report on the Surface Water and Groundwater Investigations of the Lorado Mill Area and Meteorological Data for the Gunnar Uranium Tailings, Volume 1 and 2. SRC Publication No. E-820-4-C-82.

Wigham, J.M. 1981. Personal Communication. University of Saskatchewan, Department of Civil Engineering.